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TECHNICAL NOTE

D-1320

A CENTRAL FACILITY FOR RECORDING AND PROCESSING TRANSIENT-TYPE DATA

By Staff of the Lewis Research Center

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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TECHNICAL NOTE D-1320

A CENTRAL FACILITY FOR RECORDING AND PROCESSING TRANSIENT-TYPE DATA

CHAPTER I

GENERAL DESCRIPTION

By Richard L. Smith

SUMMARY

The data system described has the capability of recording and automatically processing transient-type data in the frequency range of 0 to 10,000 cps. Data are recorded in both analog and digital form on magnetic tape and are processed by either an analog or a digital computer. Special shielded cable is used to transmit the data at low voltage levels from six test facilities over cable lengths up to 7000 feet. Identification and search features are provided as well as a quick-look feature using a storage-type oscilloscope. The system has been in operation since March 1960.

INTRODUCTION

In 1954 a central automatic data processing system was placed in operation at the Lewis Research Center (ref. 1). This system met all design objectives and is still in operation; however, it is only useful for processing steady-state-type data. Since that time, advances in the state of the electronic art have made it possible to build a data system capable of recording and automatically processing transient-type data. Increasing quantities of such data are recorded at this center as a result of experiments such as vibration testing, heat-transfer experiments, and rocket testing. The data system described in this report came as a natural outgrowth of the need for an improved means of processing transient-type data and the proven usefulness of a central automatic data processing system. This system makes possible the analysis of data by mathematical techniques that would be too time-consuming if done manually, and gives results of much greater accuracy than could be attained by older methods of processing.

Recording is done by two types of equipment, which may be classified as analog and digital. These two recording systems are independent and complement each other. The analog system has the advantage of high-frequency response, while the digital system gives greater accuracy but with lower frequency response characteristics. A block diagram showing both systems and the interconnections is shown in figure I-1.

DATA CABLE

Both types of equipment have input voltage ranges as low as ±10 millivolts full scale. The equipment accepts voltages in most cases directly from conventional low-level transducers located at the test facilities. Signals are transmitted at low level on carefully installed double-shielded telephone cable over cable lengths up to 7000 feet. By doing all voltage amplification at the central location, the test facility installation is made relatively inexpensive and more reliable. In most cases the test facilities can use already existing instrumentation.

Figure I-2 illustrates the method of connecting test facilities to the central data facility. A single 200-pair data cable is shared by all test facilities. A 400-contact relay at each test facility connects transducers at that facility to the data cable only while the facility is recording data. At this writing six test facilities use the central transient data facility.

DIGITAL SYSTEM

The digital recording system has 128 input channels. Resolution to which voltages are measured is 0.1 percent of full-scale voltage. Overall system accuracy is approximately 0.25 percent of full-scale voltage. The digital recording system differs from the analog system in that input voltages are not recorded continuously, but are sampled in rapid sequence, converted to a digital form, and recorded serially on tape as binary encoded numbers. The basic sampling rate is 4000 samples per second; if 10 channels of data were being recorded, each channel would be sampled 400 times per second.

Reading, program, facility, and channel identification are provided. A block number, which is an elapsed time indication, is written digitally at intervals of 8 to 32 milliseconds, depending on the number of channels being recorded.

An extremely versatile and useful quick-look feature is provided for system checkout and editing purposes as part of the digital playback equipment. Digital data signals are converted back to analog form and displayed on a storage-type oscilloscope as a plot of any selected single channel against time, an X-Y plot of two selected channels, or a bar-graph-type presentation of all channels. When used in system checkout, the digital signals are retrieved from a point in the recording system just ahead of the record heads, so that a good check of recording system operation is obtained. When used as an editing feature, a separate playback tape handler is used. By using the block number identification on tape in conjunction with the playback search features provided, any portion of data on the tape may be quickly and precisely located and displayed.

In addition to providing the quick-look function, the digital playback equipment serves as an input to a high-speed digital computer to which direct connections are made. Provision is also made for inputs to an analog computer, X-Y plotter, and oscillographs.

A photograph of the digital system is shown in figure I-3. The analog computer used in conjunction with both systems is presented in figure I-4.

ANALOG SYSTEM

The analog system is capable of recording 24 variables simultaneously on its 24 input channels. The method of recording is frequency modulation of a high-frequency carrier. The accuracy to which a d-c voltage applied at the sending end can be recorded and played back is 1 percent of full-scale voltage. Frequency response of this system is $\pm 1/2$ decibel from d.c. to 10,000 cps exclusive of the input cable characteristics. The cable characteristics have the effect of degrading this frequency response at the high-frequency end; this is discussed more fully in chapter II.

Since several facilities may be recording data on a single reel of magnetic tape, it is important to provide positive identification for the recorded data. For this reason a reading number and a facility number are recorded in a digital form preceding each reading. Time from the start of each reading is recorded digitally at 50-millisecond intervals at the highest recording speed and at longer intervals at slower speeds. Known standard voltages are recorded preceding each data reading, and this information is used when playing back to correct automatically for d-c drift in the recording equipment.

On playback, search features are provided for automatically locating any desired reading and any desired position on the tape within a reading. A quick-look feature is provided using a storage-type oscilloscope on which up to 12 channels of data may be viewed simultaneously. Up to 24 channels of data may be played back and plotted simultaneously either locally or remotely on plotting equipment. These data may be either raw data or data on which analog computations have been performed. Playback may be done at 1/4, 1/2, 1/8, 1/16, and 1/32 of normal recording speed in addition to normal recording speed.

A photograph of the analog system (fig. I-5) shows the control console with storage oscilloscope in the foreground.

REMARKS

The reasons for some of the basic decisions in planning the central data facility described in this report that might be of interest are listed herein.

One of the first decisions made was the type of recording to be used. Frequency-modulated analog recording offered the capability of wide bandwidth, while high-speed digital recording incorporated much higher accuracy and compatibility with a digital computer at the cost of bandwidth. Pulse-width modulation-type systems had neither the accuracy of digital systems nor the bandwidth capability of a frequency-modulation system. By incorporating both digital- and frequency-modulation-type recording equipment into one transient data recording facility, a maximum range of test facility requirements could be met.

From the standpoint of both cost and ease of maintenance, it is desirable to concentrate all complex electronic equipment at the central recording location. For these reasons, it is desirable to transmit signals from the test facilities to the central recording facility at voltage levels generated by the transducers and do necessary voltage amplification at the central location. The problem of sending analog signals as low as 10 millivolts full scale over long cable distances without loss of accuracy seems formidable. However, preliminary tests on already existing telephone cable installations at this center, together with the availability of amplifiers having differential input terminals isolated from ground, indicated this could be done. This approach of doing all voltage amplification at the central location was carried out and proven to be extremely successful. A more complete discussion of the cable installation is given in chapter II. It should be pointed out that the alternative approach of amplifying a signal at the test facility and sending it at a higher voltage level to a remote recording location presents problems that are not at first obvious. If this is done, the amplifier output must be isolated from ground or else the recording equipment input terminals must be isolated from ground. In addition, the amplifier must be able to drive a capacitive load without becoming unstable, a capability that many commercially available d-c amplifiers do not have.

Several methods were considered for providing a digital recording system having in excess of 100 channels. One method is to provide an amplifier for each channel and electronically multiplex the amplifier outputs into an analog-to-digital converter. This is a practical method; however, it results in an extremely costly and complex data system if a large number of channels are involved. Multiplexing signals at low voltage levels into a single amplifier or a small number of amplifiers results in a more inexpensive and less complex system; however, the problem of switching low voltages at high speed is a difficult one. Mechanical switching devices provide all the accuracy necessary but present problems in operating at the speeds required. Electronic switching devices for switching small voltages without introducing noise in excess of 10 microvolts were nonexistent at the time this data system was being constructed, although at the present time transistor switches appear to be approaching this requirement. This problem was solved by using a mechanical multiplexer consisting of a rotating magnet operating switch capsules located around the periphery of the multiplexer. The multiplexer operates at a speed of 500 contact closures per second and is described in chapter IV.

Considerable emphasis was also placed on complete identification of data on the recording tape to facilitate searching for areas of interest when playing back data for quick-look or computer entry.

Two general types of digital tape format were considered before a decision was made as to type of format to be used. When entering information into a digital computer at high speed from magnetic tapes, the tape handler must be stopped at regular intervals to allow time for computations to be performed before the next block of information is entered. If information is recorded continuously on the tape, the tape handler must reverse a short distance before reading the next block of information into the computer to avoid skipping information when the tape handler is stopped and started. To simplify computer entry a commonly used computer tape format provides gaps between blocks of information the computer can absorb at one time. The decision was made, however, to record data continuously on tape to preserve the capability of easily reconstructing the original analog data signal intact from the digital data tape for purposes of analog computation, quick-look, or analog plotting.

In any sampled data system, it is true that a phenomenon known as "aliasing" may occur if frequencies exist in the signal that exceed half the sampling rate of the data system. This means that a false frequency appears in the sampled data that did not exist in the signal. For example, a 60-cycle signal, sampled at 59 cps, would appear in the sampled data as a 1-cps sine wave having the amplitude of the true signal. A signal frequency an exact multiple of the sampling frequency would appear in the data as a d-c signal. A method of correcting this problem is to place a low-pass filter in series with each input line such that all signal frequencies higher than half the sampling frequency are eliminated.

While filtering of individual channels has been done in some cases to eliminate troublesome high frequencies, filters were not incorporated as an integral part of this data system for the following reasons: If the wide flexibility of sampling rates, which is a useful feature of the system, was to be retained, the number of filters required would be large, and the methods of switching in the proper filter to match the sampling rate would become complex. In addition, removing the higher frequencies by filtering may remove useful information from the data. Although aliasing has not presented a serious practical problem, it cannot be ignored, and solutions that do not involve removing information from the signal are being investigated.

EXPERIENCE AND USES OF SYSTEM

The first application of the central transient data recording system was in processing the data from the first Big Joe Project Mercury test in September 1959. The system was not intended for processing data of this type, and its construction was not complete at that time. However, because of the availability and applicability of the equipment and high priority of the job, the equipment was used successfully.

Operation of the data system as a central recording system began in March 1960. Approximately 1000 data readings were made in the first 18 months of operation. Loss of data due to central data equipment malfunctions has been less than 1 percent in this period of time. Records of unscheduled down time are not available; however, the history of the equipment has been very good in this respect.

Almost all data processed through the data system have resulted from various types of rocket tests. Heat-transfer tests and rocket performance tests make up the bulk of these. The short duration of these tests makes the use of transient-type recording equipment mandatory. In order to extract the most data with a minimum of testing, automatic programming of the rocket through two or more modes of operation is often carried out during a single rocket run. When a facility requests it, on-line computation is performed using the analog recording equipment and an analog computer and is made available to the test engineer immediately after each test run in order that a rough check may be made of results as the test proceeds. More accurate and detailed digital computations are performed on data recorded on the digital recording system and are made available at a later time. In some cases where a continuous analog computation made over a complete run is more useful than a digital tabulation of computed results, the data have been processed by recording on the digital system and then playing this information back through the analog computer.

At the present time thought is being given to modify the digital system in two areas. The differential input amplifiers presently being used in this system are the largest source of system error and will be replaced soon by amplifiers of more advanced design. The mechanical multiplexer has performed well in the system from the standpoint of not degrading the accuracy of the system; however, periodic maintenance is required to locate and correct switch capsule failures. Transistorized low-voltage multiplexers are being investigated at the present time.

At this writing, six facilities are connected to the central system at the Lewis Research Center. A remote recording system, the same type as the one at Lewis, is located at the Plum Brook rocket test site near Sandusky, Ohio. This system uses the Lewis playback editing and computing equipment and records data from at least eight other facilities.

REFERENCE

1. Staff of the Lewis Laboratory: Central Automatic Data Processing System. NACA TN 4212, 1958.

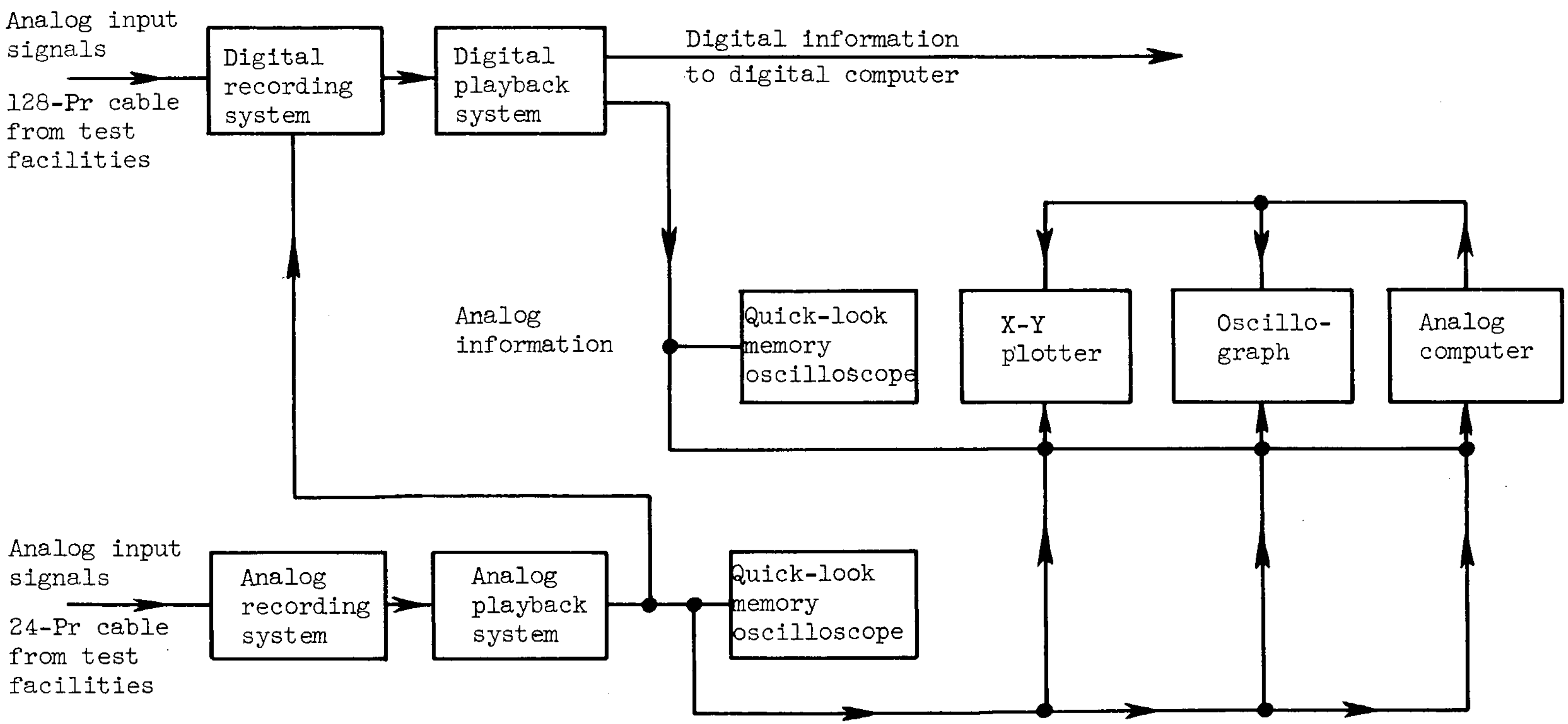


Figure I-1. - Central transient data facility block diagram.

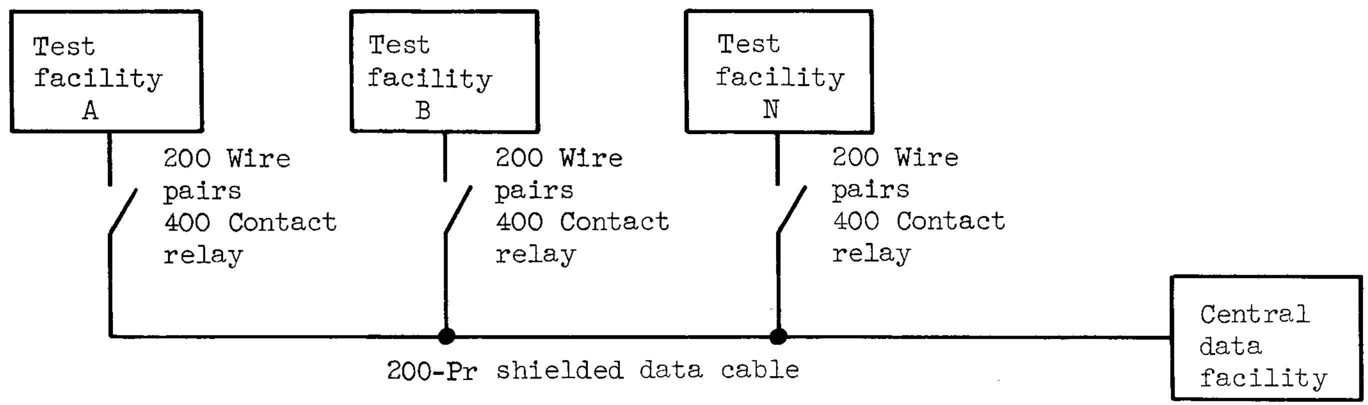


Figure I-2. - Data cable installation.

Figure I-3. - Digital system.

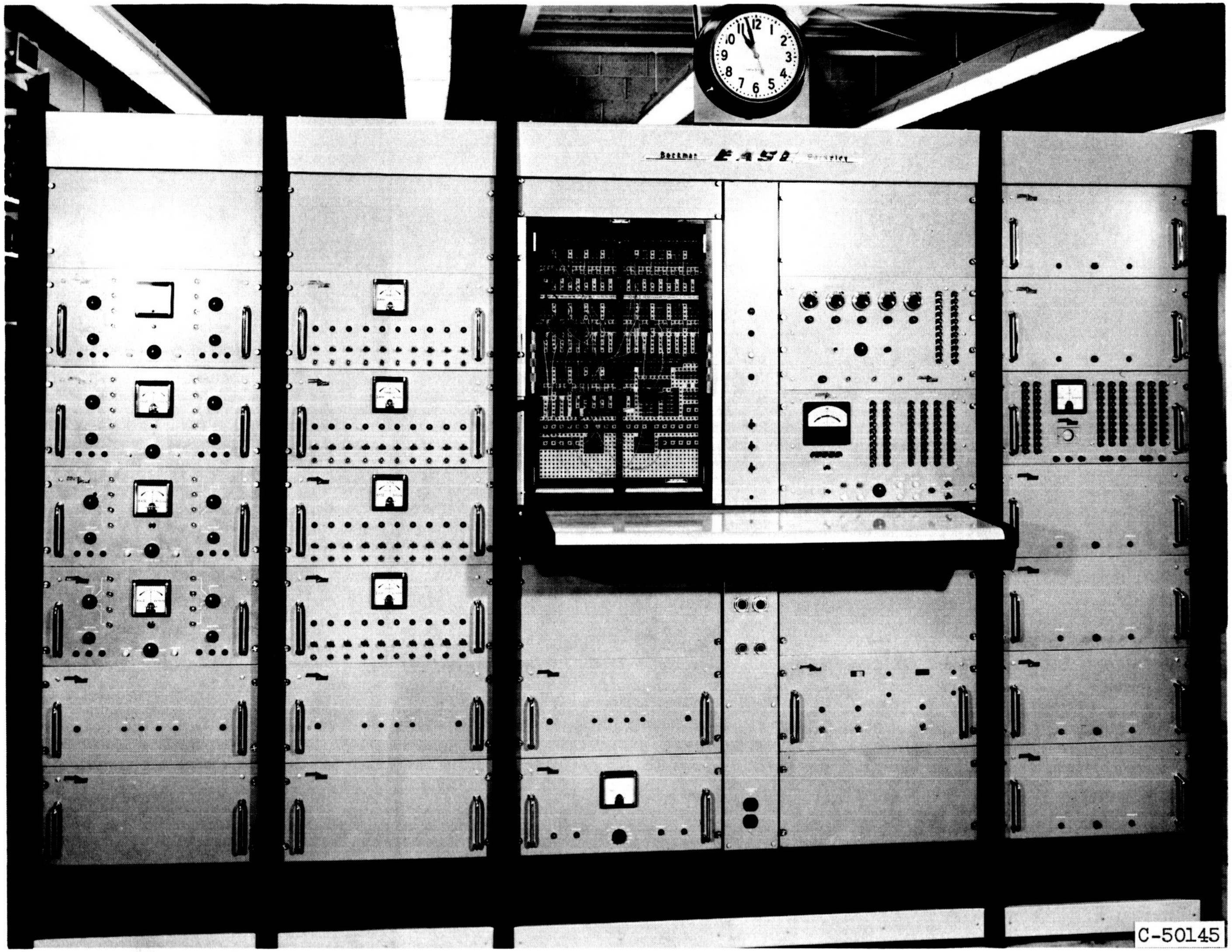


Figure I-4. - Analog computer.

Figure I-5. - Analog system.

CHAPTER II

TRANSMISSION OF LOW-LEVEL VOLTAGE OVER LONG TELEPHONE CABLES

By Richard L. Smith

The problems encountered in transmitting low-level transducer signals over long lengths of telephone cable - as in the case of the installation described herein, lengths up to 7000 feet - may be divided into two general classifications. One of these problems is the effect on the signal of the electrical characteristics of the cable itself, and the other is the addition of extraneous electrical noise to the signal.

The first of these problems has nothing to do with the fact that the signal is being transmitted at low voltage levels, since an equal percentage of distortion of the signal would result if it were transmitted after amplification, assuming the amplifier to have the same output impedance as the transducer. At low frequencies, the only effect of the cable is that of its resistance. The resistance of 7000 feet of No. 19 wire is 56 ohms, so that the total loop resistance of the cable is 112 ohms, resulting in an attenuation of the signal of about 0.11 percent of the signal when using amplifiers having a 100,000-ohm input impedance at the central location.

A more serious problem is that of distortion of high-frequency signals due to distributed capacity and inductance in the cable. Figure II-1 shows the attenuation and phase shift characteristics of 10,000 feet of the specially shielded cable used in this installation without loading or equalization to correct for cable parameters. The measurements were made with the cable terminated in 100,000 ohms and an assumed zero impedance voltage source. These results apply when using a voltage source having a very low internal impedance. If the voltage source has some internal resistance, the input impedance of the cable has an effect on the frequency response curve at higher frequencies. Figure II-2 shows input impedance of 7000 feet of cable plotted against frequency. This impedance is largely capacitive reactance. Since this impedance drops off at high frequencies, the larger currents drawn from the transducer at these frequencies cause a voltage drop in the internal impedance of the transducer. The effect of this is shown in figure II-3, which is a plot of E_{out}/E_{in} against frequency for various values of internal generator resistance, where E_{in} is the internal voltage of a generator attached to a 7000-foot-long cable and E_{out} is the voltage appearing at the output of the cable. As these curves indicate, a transducer having internal resistances higher than 100 ohms might require the use of an amplifier having a low output impedance if frequencies up to 10 kilocycles were to be recorded. Since the nature of the testing done at the facilities using this data system has not required the analysis of signals having high-frequency components, there has been no need to use amplifiers to gain a better frequency response.

One source of electrical noise in a data system is noise introduced between the transducer and the recording instrument because of extraneous electrostatic or electromagnetic pickup in the connecting cable. When low-impedance transducers of the order of a few hundred ohms are used as voltage sources, the effect of electrostatic noise is usually negligible, except for noise occurring at frequencies high enough that it can be easily filtered without destroying the character of the signal.

Electromagnetic noise pickup is a more common problem and usually appears as signals of 60, 120, or 180 cps, resulting from the data cable being placed in a magnetic field created by wires or equipment carrying heavy currents at power frequencies. Since the data signals also contain these frequencies, the problem cannot be solved by filtering. Noise of this type can be minimized by using twisted-pair cable conductors, by shielding the cable with a magnetic material, and by routing the cable so that it is not in close proximity to power cables or equipment. All three of these methods were used in the central data installation described herein. The cable used was made to order for this installation with both electrostatic and electromagnetic shielding. A cross section of the cable is shown in figure II-4. The cable was installed underground where possible to provide additional shielding. Noise measurements on a 5000-foot length of installed cable indicated that the noise level on the cable was less than 5 microvolts peak to peak, which was the smallest amount that could be detected with the amplifiers available.

Measurements of cross talk between adjacent cable pairs in 7000 feet of cable show less than 0.024 percent cross talk at frequencies up to 10 kilocycles when transducers are floating with respect to building ground and isolated from each other electrically. When a transducer that is generating a cross-talk voltage is connected to building ground, however, a transducer that has an impedance unbalance to building ground may receive an appreciable amount of cross-talk voltage, as shown in figure II-5. This has not been a practical problem in the use of this data system since transducers in use here, of the types capable of generating frequencies high enough to create cross-talk problems, namely strain-gage types, do not need to be ground referenced.

A second type of noise is introduced by so-called common-mode signals. This problem arises when the transducer is not isolated electrically from building ground. If the transducer is ground referenced, obviously the amplifier input terminals must both be isolated from ground; otherwise, any small voltage differences between the two ground points appear across the amplifier input terminals. Even when assuming that the amplifier terminals are perfectly isolated from ground, however, connecting a long telephone cable to a grounded transducer may introduce electrical noise. The reason for this is shown in figure II-6. A transducer, represented by voltage E_T and internal resistance R_T, is grounded and connected across a cable input pair. These wires will each have a large capacity to the cable shield represented by C_1 and C_2. Any difference in potential E_C between cable shield and transducer ground will cause currents I_1 and I_2 to flow through C_1 and C_2, respectively. The value I_1R_T represents a noise voltage that appears across the amplifier input terminals regardless of how well they are isolated from ground. If C_1 is 0.1 microfarad, R_T is 500 ohms, and E_C is a 60-cycle signal, $E_C/50$ will appear as noise across R_T. In other words, a data system that is sensitive to a 10-microvolt signal will detect a 500-microvolt potential between shield and transducer ground in the configuration described. This effect can be nullified by inserting a resistor equal to R_T in series with the other connection to the cable termination; however, this solution is rather tedious if large numbers of transducers are involved. The best solution is to continue the cable shield as close to the transducer as possible and make its ground point as near as possible to the transducer ground. Since the data cable is shared by several facilities, the data cable shield is not connected to any ground except during the time data are being recorded. At this time a relay contact connects the cable shield to the transducer ground of the facility that is recording data. Measurements of noise, even with proper grounding precautions taken in the data system, caused by this cable capacity effect have been as high as 50 microvolts peak to peak with a transducer unbalance to ground of 1000 ohms.

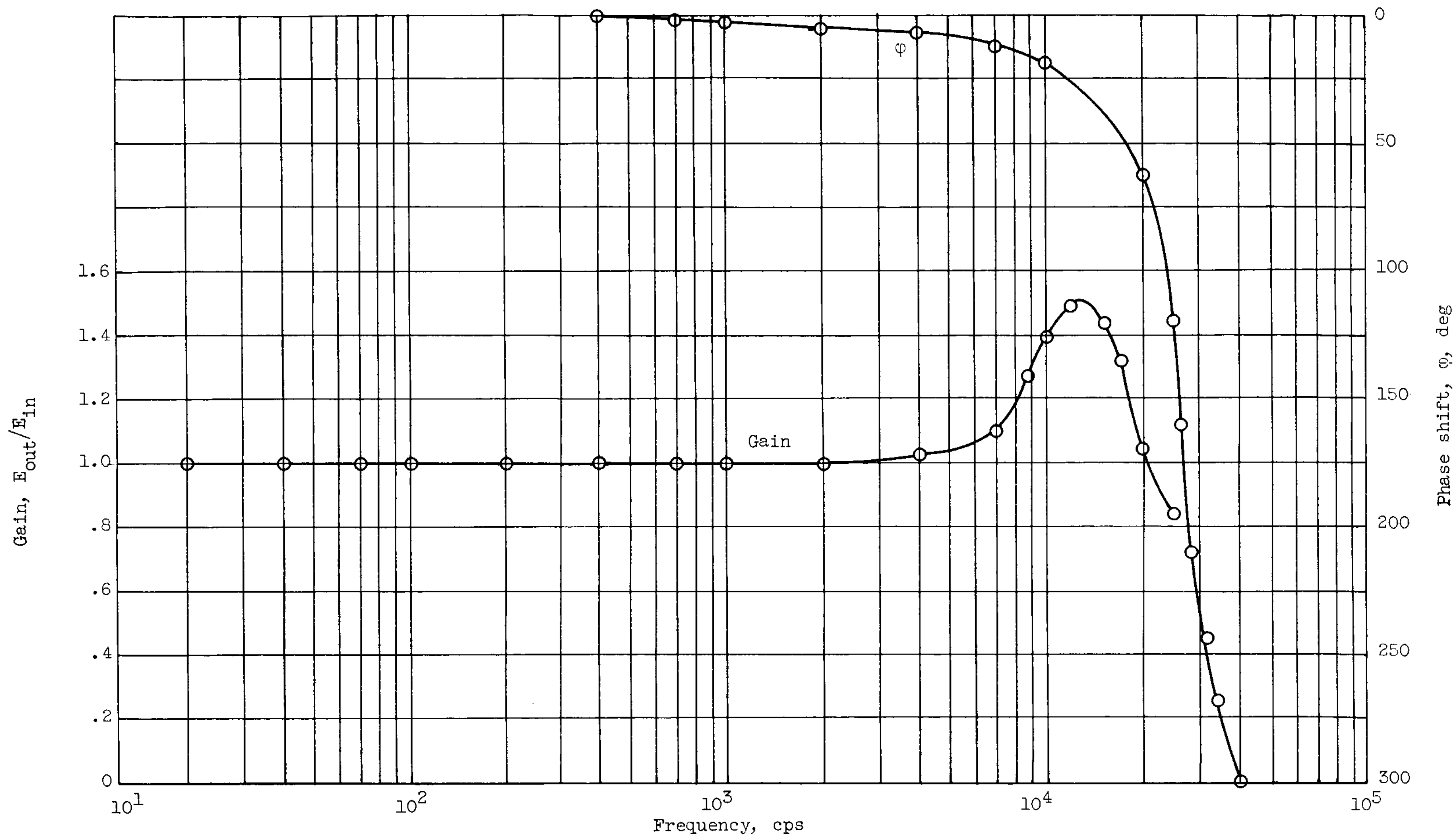


Figure II-1. - Characteristics of 10,000-foot-long telephone cable.

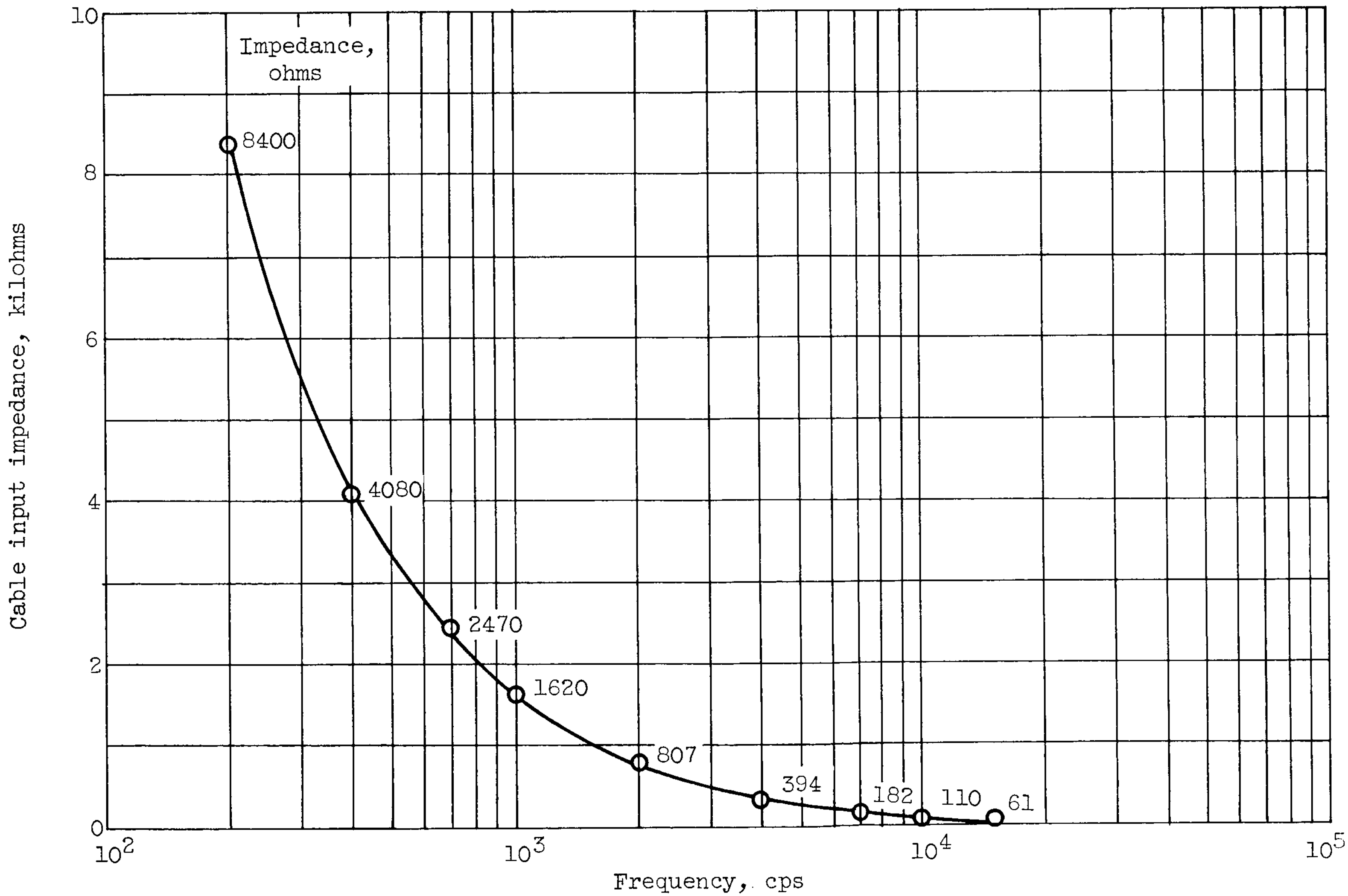


Figure II-2. - Input impedance of 7000-foot-long cable.

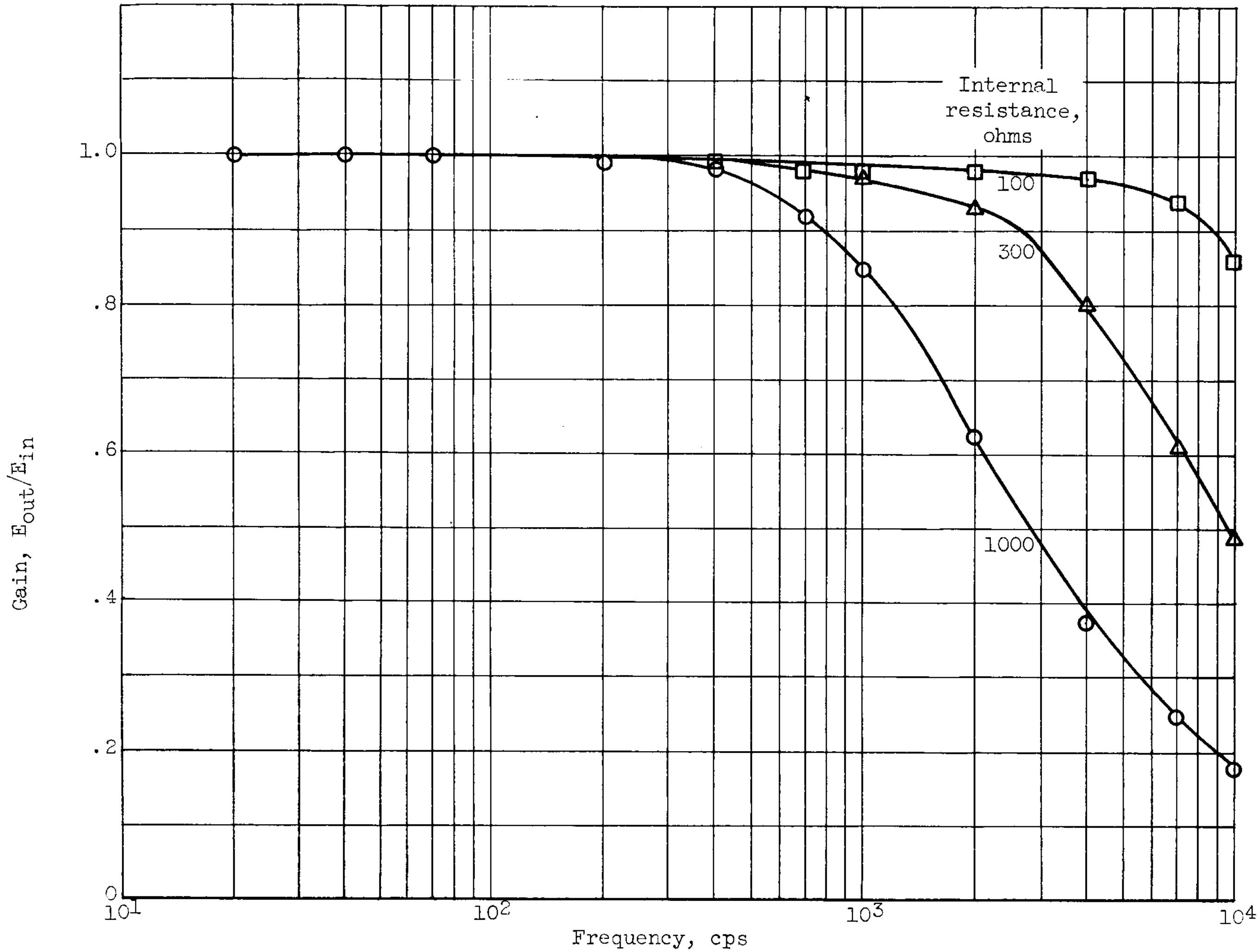


Figure II-3. - Characteristics of 7000-foot-long cable and voltage generators with 100-, 300-, and 1000-ohm internal resistance.

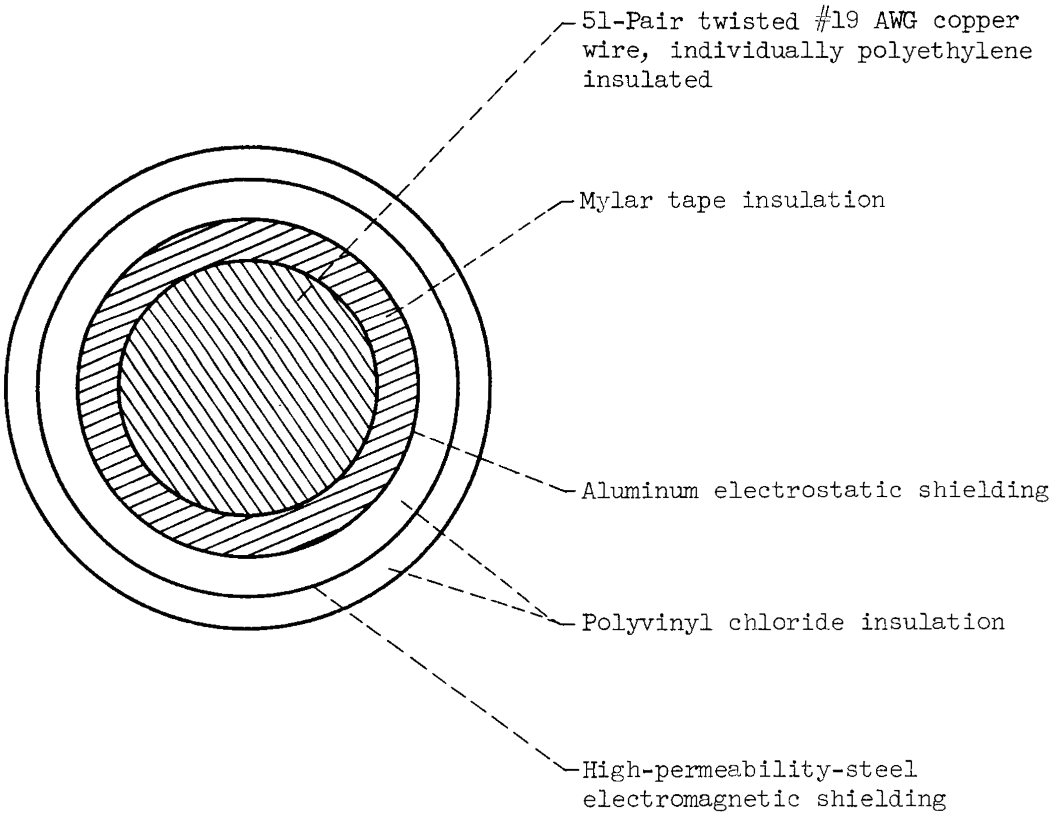


Figure II-4. - Shielded cable cross section.

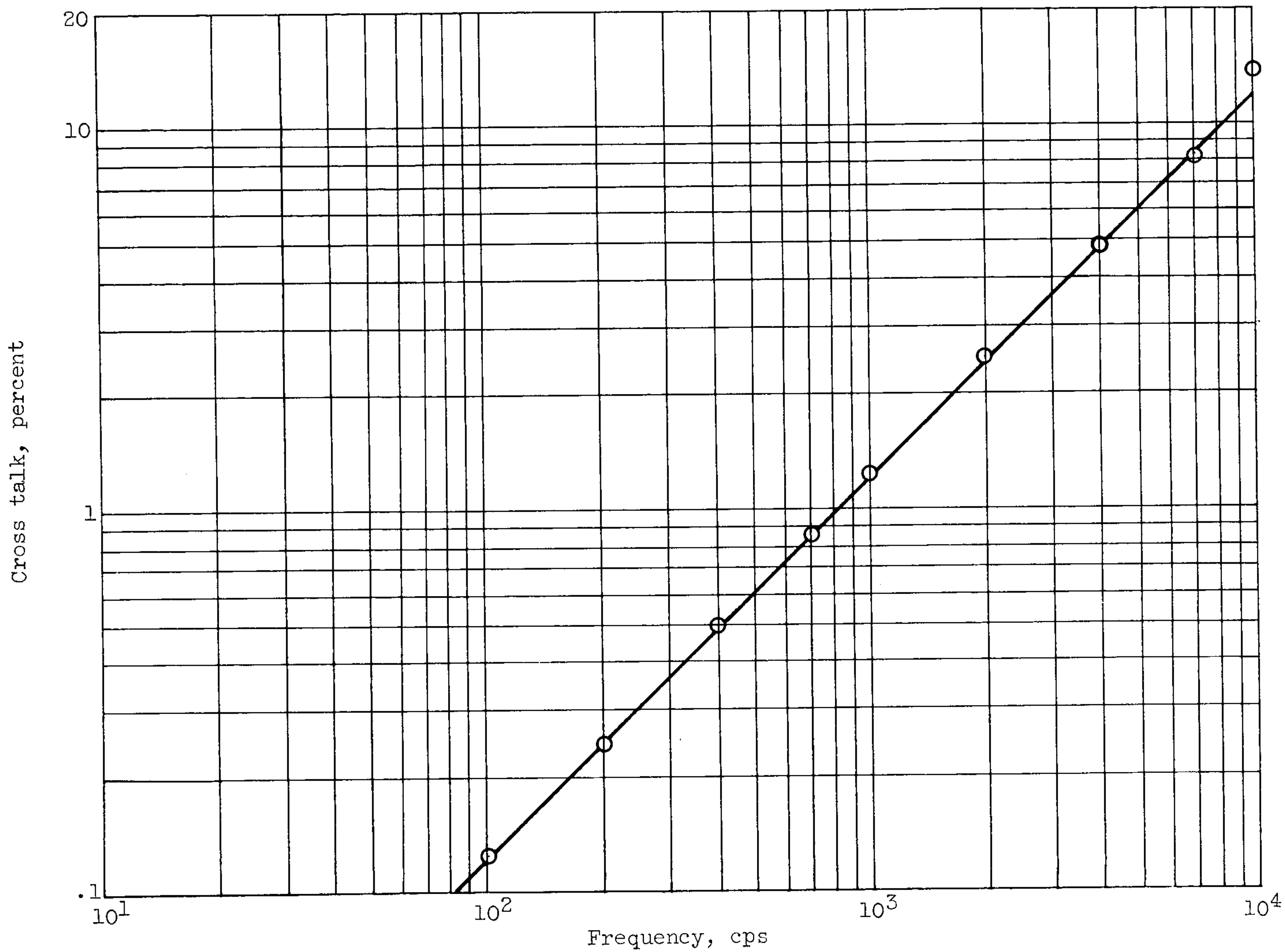


Figure II-5. - Cross talk into 100-ohm unbalance to ground in 7000-foot-long cable.

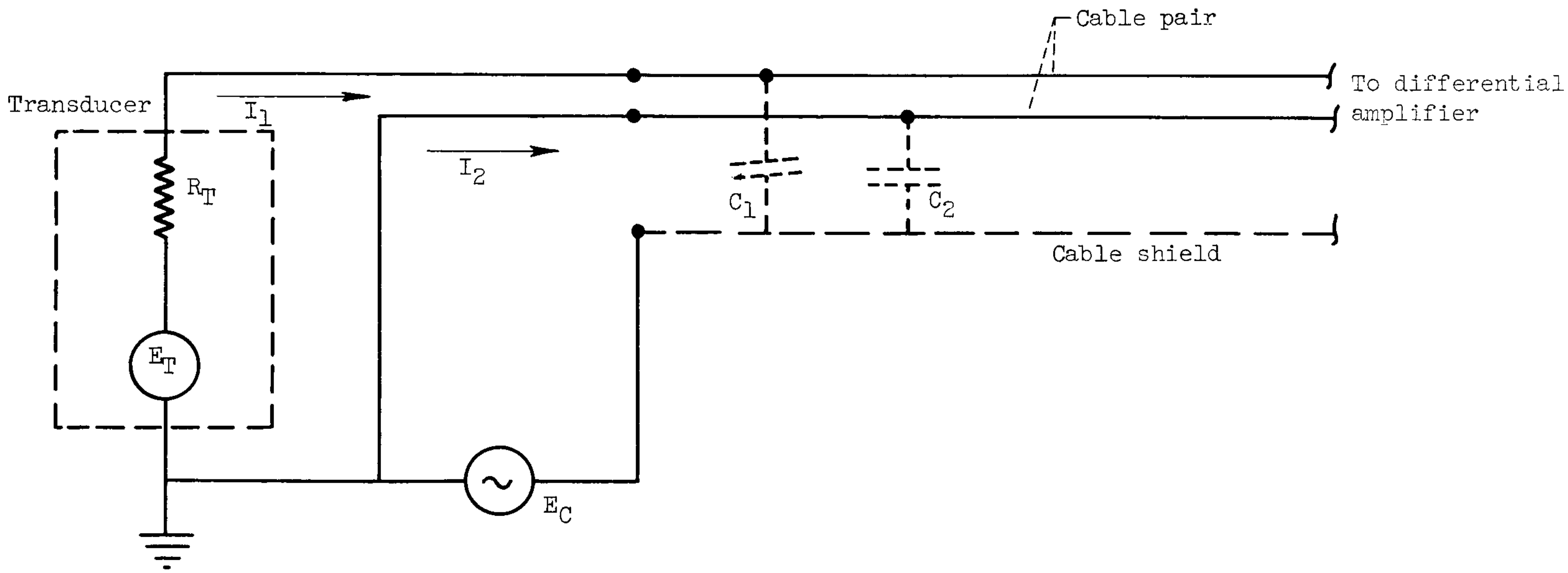


Figure II-6. - Noise introduced by voltage between cable shield and transducer ground.

CHAPTER III

DIGITAL SYSTEM

By Charles W. Mealey, Jr., and Leslie G. Kee

DIGITAL RECORDING SYSTEM

Block Diagram

The prime function of the digital recording system is to accept transducer-level analog voltages from any one of several remote test facilities, amplify and convert the analog signals to a binary digital form, and then record the digital information on magnetic tape for convenient entry into a digital computer. The input signals to be recorded are transmitted at low voltage levels by specially shielded cable, described in chapter II, from the test facility to the central recording system. The two basic sampling rates of the system are 4000 and 1000 per second. The system can handle 1, 2, 3, 4, 5, 6, 7, 8, 32, 64, and 128 inputs. The sampling rate per input is equal to the basic sampling rate divided by the number of inputs. The input voltage ranges are 10, 20, 50, 100, 200, and 400 millivolts full scale.

Figure III-1 is a block diagram of the digital recording system, which is made up of the following units:

(1) An input plugboard on which are terminated various signal and control circuits for selection by an operator

(2) A mechanical premultiplexer, which makes 128 signal inputs available eight at a time to the recording system

(3) Eight input amplifiers, which raise the signal level for storage

(4) Eight analog storage units, which store the eight signals, and a main multiplexer, which time-shares the storage unit outputs into the analog-to-digital converter

(5) An analog-to-digital converter, which generates a digital representation of the analog input signal

(6) An ancillary code generator, which generates codes identifying the recorded data

(7) Writing electronics, which assembles data and coding in a recording format

(8) A digital magnetic-tape handler for recording the data

(9) A recording monitor, which is used to monitor recordings in progress and provide equipment checks

(10) Master programming and control, which is used to control and synchronize the entire recording process

Each unit of the digital recording system is discussed in detail in the following sections.

Input Plugboard

A 1632 contact plugboard provides a quick means of changing signal paths, equipment programming, and system control. Multiple terminations on the plugboard allow a high degree of flexibility in the use of the signals. For example, the amplifier outputs are terminated in triplicate. One output normally supplies the main multiplexer; another is used for oscilloscope observations. The remaining output has been used to supply the analog recording system with high-level signals. Where both input and output of a device are terminated, spare units may be easily substituted by replugging the board in case of failure.

A separate plugboard is provided for each facility or test area. Thus, replacing one plugboard with another can rapidly change signal routes, facility connections, coding, and programming. An important additional feature of the plugboard is the provision for connections between the analog and digital systems.

Premultiplexer

The term multiplexer, as used in this report, implies a device used to switch a large number of input circuits into a smaller number of output circuits on a time-sharing basis. The use of a low-voltage-level mechanical multiplexer at this point in the system is advantageous to reduce complexity of the system, the alternative being to use an amplifier in each channel and multiplex at high voltage levels at the amplifier outputs.

The premultiplexer switches 128 two-wire circuits to eight two-wire circuits, sequentially. Figure III-2 shows the switching circuit configuration. The switching sequence follows a pattern of the simultaneous closure of switches 0-7, 8-15, 16-23, and so forth. This multiplexing is accomplished by rotating magnetic poles operating the switches. Figure III-3 illustrates the arrangement of the magnetic structure and switch positions. The switch capsules are attached to the multiplexer housing and thus are stationary. The armature of the switch capsule is a magnetic material and moves toward the closer field pole as both of the magnets rotate together, thus the switch action.

The switching period of 2 milliseconds is a function of the size of the slot and post configuration of the magnets and the rotation speed of the magnets. The switch operating time varies between 100 and 200 microseconds. In addition, the switch period jitters or varies about 150 microseconds in time with respect to the drive motor line frequency. Any group of eight switches is closed simultaneously at least 1.6 milliseconds, which is sufficient time for the amplifiers and main multiplexer to make an accurate sample of the data. The synchronous drive motor operates on 500 cycles derived from the clock pulses, generated by a crystal-controlled oscillator.

Individual switches are hermetically sealed and are easily replaceable. There is virtually no contact bounce as a result of oil damping. The electrical noise introduced by the switches is negligible because of symmetrical lead wiring and circuit configuration. The contact resistance of each switch is about 0.5 ohm. Consecutively operated switch contacts are nonbridging.

An important additional feature of the premultiplexer is a set of timing signals. These signals are generated, as illustrated in figure III-3, in adjustable pickup coils by fringing flux at scratch marks on the periphery of the outer magnet. One use of these timing signals would be to control the readout of the premultiplexer. Because of the jitter and possible drift of the motor driving the multiplexer, this use of the timing signals would result in irregular spacing in time of the data samples. To preserve the exact time relation of events recorded on tape, another method was chosen. In this system, the premultiplexer is read out at precise intervals controlled by clock pulses from a crystal-controlled oscillator. The timing signals are used, however, for checking synchronization of the premultiplexer with other system units. Figure III-4 is a photograph of the complete premultiplexer with an inset showing a single switch capsule.

Input Amplifiers

The commercially available amplifiers in this system have full-scale input level steps of ±10, ±20, ±50, ±100, ±200, and ±400 millivolts at an input impedance of 100,000 ohms. The full-scale output level is ±10 volts, capable of delivering 20 milliamperes to a load. The gain error is less than 0.1 percent of full scale, and the gain is stable to 2 microvolts, referred to the input, in 40 hours. With shorted input the noise is less than 5 microvolts rms, referred to the input. The amplifier frequency response is from d.c. to 3 kilocycles (-3 db at 3 kc). Response time to an input step function is 500 microseconds to be within 0.1 percent of the new level. Overload protection is incorporated such that ±10 volts input causes no more than ±15 volts output with a recovery time less than 500 microseconds. Also, circuit failure in the amplifiers will cause no greater than a 20-volt output. The amplifiers are of the differential input type and have a common mode rejection greater than 10^6 at 60 cps with 1000-ohm unbalance. This latter characteristic is of considerable importance in this system.

Since the signal transducer is distant from the amplifier, a difference of potential exists between the amplifier ground reference and the transducer ground reference. Use of a single-ended amplifier would result in an output voltage proportional to the sum of the transducer voltage and the ground difference voltage. Thus, a differential amplifier that amplifies only the difference of voltage between its inputs is necessary to reject the common input voltage. Figure III-5(a) illustrates a typical application of a differential amplifier.

The term common mode rejection can be defined as a measure of insensitivity of the amplifier to signals common to the two input terminals, termed common mode signals. The common mode rejection can be calculated as the ratio of the differential signal gain of the amplifiers to the common mode signal gain. Measurement of the common mode signal gain can be made using the circuit of figure III-5(b). An unbalance of 1000 ohms is inserted to simulate the worst possible situation if transducers having up to 1000-ohm output impedance are in use. To reject a common mode signal of this sort, the amplifier input terminals must not merely have balanced internal impedances to amplifier ground, but must have extremely high impedances to ground.

Figure III-5(c) indicates the method used in this system amplifier to achieve good common mode rejection. Here a single-ended amplifier and a modulator are enclosed in a shield driven at the common mode signal level. The physical capacity between input wiring and shield is rather large; but, since the shield is driven at common mode potential, the effective capacity of input terminals to ground becomes very small. D.c. isolation is achieved through the use of transformer coupling between the amplifier-modulator and the demodulator.

Storage and Main Multiplexer

The storage and main multiplexer unit stores simultaneously the eight analog outputs of the amplifiers and presents them one at a time to the analog-to-digital converter input. The simultaneous storage results in a time correlation of the eight storage circuits to one output circuit on a time-sharing basis similar to that of the premultiplexer.

Referring to figure III-6, the operation of a single unit is as follows:

(1) Switches S_2 and S_3 close, completing loop 2. This allows capacitor C to store a charge proportional to the input voltage.

(2) Switches S_2 and S_3 open simultaneously with the closing of switch S_1. This prevents amplifier A from saturating, keeping the summing point $\sum$ at 0 volt.

(3) Switch S_3 is then closed, connecting the cathode follower to the output, making the voltage on C available to the converter.

Analog-to-Digital Converter

The converter, a commercially available unit, is an 11-bit (binary digit) binary unit with a ±10-volt input represented by a total decimal count of 2047. The conversion is made by approximating the input by successive comparisons in the sequence 1/2, 1/4, 1/8, and so forth, full-scale values. In order that signals of both polarities can be converted easily, the ±10-volt input signals are amplified and rereferenced with the linear correspondence of -10 to 0 volt and +10 to +200 volts. In the example shown in figure III-7, an input voltage of +4.300 volts corresponds to +143.00 volts. A series of 11 electronic switches operated by flip-flops supply voltages for comparison with the rereferenced inputs. The switches are turned on one at a time and remain on if the sum of their voltages is less than the input and are turned off if otherwise. After the last comparison is made, the condition of the flip-flops represents the input in digital form. A single conversion is made in 22 microseconds.

At low speed the unit is cycled at 1000 conversions per second and at high speed at 4000 per second. The high-speed cycling rate is limited by tape-handler speed and longitudinal packing density on the tape. The conversion is accurate to within 0.05 percent ±1/2 the least significant bit. The output consists of 11 lines energized at one of two voltage levels representing logical "1's" or "0's". These digital lines transmit information to a series of gates in the write circuits.

Tape Format

The data are recorded on standard 1/2-inch Mylar-base magnetic tape. A modified-saturation nonreturn to zero recording is used in which a binary "1" is indicated by a change of flux from one saturation level to the other, and a binary "0" causes no change in the polarity of magnetic saturation of the tape. Eight tracks are used to record the data with a packing density of 200 bits per inch per track.

The bit structure of the recording is shown in figure III-9. A transverse line of bits, one bit in each track, is defined as a frame. Three frames are needed to describe one word of data completely. The binary data bits are recorded in the position indicated by the Arabic numerals one (1) to ten (10) and the S position. The numeral one (1) is the highest order data bit, the numeral ten (10) the lowest order data bit; and the s position indicates the sign of data. The seven Roman numerals indicate the position of the word number bits with one (I) being the highest order bit and seven (VII) the lowest order bit. A frame parity check bit is recorded in track 7 so that the sum of "1's" in tracks 1 to 7 is always an odd number. Thus, if the sum of "1's" in the first six tracks is an odd number, a "0" is recorded in track 7.

Ancillary Coding

Ancillary coding is recorded in a serial form in track 8. Figure III-10 shows the grouping and pulse position pattern of this information. First, notice that this information is recorded at an "every other frame" rate. The exception is the pulses that are recorded in frames 1 and 2. These two pulses thus serve to identify the beginning of the recording of a block of information.

The next 17 pulses, the first being located in frame 4 and the seventeenth located in frame 36, are a binary recording of block number. A pulse in its frame location indicates a binary "1," and the absence of a pulse indicates a binary "0." A block of data is a grouping of 32, 64, or 128 data words. Each block of data is numbered in sequence starting with one from the beginning of a reel of magnetic tape. It is this number that indicates real data time during the recording of an event. The block number is used in editing to identify the areas of interest to be computed. Bit (1) of the block number located in frame 4 is the highest order block number bit, while bit (17) is the lowest order bit.

The next 12 pulses located in frames 38 to 60 indicate reading number in a binary decimal code. A reading of data consists of any number of blocks of data needed to record a data event from one facility. Thus, a reading is bounded at the beginning by the start of recording from a facility and at the end by the stopping of the record equipment after the data event.

A binary code of five bits is recorded in frames 62 to 70 which identifies the facility from which the data are being taken. This gives an identifiable capacity of 31 different facilities.

Computer program identification information is recorded in binary decimal form in frames 72 to 92. This coding is used by the digital computer to verify the correct program from storage so that the recorded data may be processed. Frame 94 is the index bit and is always in a binary "1." This is used in the control logic in playback of the recording.

The number of frames necessary to write the complete line of ancillary information dictates a minimum block length of 32 words. If 64 or 128 signal inputs to the equipment are used, the block length becomes 64 or 128 words; and the additional time in the ancillary track is unused. By recording all ancillary information every block, rather than only at the beginning of the reading, it is possible to start processing data from any location within the reading.

Write Circuitry

Figure III-8 is a block diagram of the writing circuitry including a block for parity generation. The input levels (I-VII) supplying word number indication are determined by the position of the main multiplexer and the premultiplexer. The input levels (s-10) come from the analog-to-digital converter and represent the value of the analog signal in digital form. The ancillary code levels are supplied from the ancillary code generator. The clock pulse shifts a binary "1" around the ring-of-three counter beginning with the A flip-flop. When the "1" is in the A flop-flop, the first line of AND gates is enabled. Those inputs that are binary "1" are transmitted through the OR gates to the parity generator and to the AND gates at the right of the diagram. The parity output as well as the ancillary code is applied to the same line of AND gates. Binary "1's" appearing at the inputs of these AND gates enable the next clock pulse to change the state of the flip-flops. The flip-flops control the direction of current through the record heads. Thus, the magnetization of the tape is changed for binary "1's" at the inputs.

At the time the clock pulse was gated to the flip-flops, the "1" in the A flip-flop was shifted to the B flip-flop, and the second set of AND gates was enabled to write another line of information on the tape. This process continues through the C flip-flop and is repeated for each word written on tape.

Magnetic-Tape Handler

The data are recorded in eight tracks on 1/2-inch tape at either 15 or 60 inches per second. Recording with the premultiplexer is restricted to high speed because of the difficulty in a 4-to-1 speed change for the 500-cycle motor. When using only the main multiplexer, both high- and low-speed recording are practical. The handler is of the digital type and is operated by pulse commands. The start and stop times are less than 5 milliseconds.

Operation

Telephone or intercom communication prior to and during the recording is a necessary part of operation. Operational control is effected by relays operated by the recording facilities over telephone lines. A typical procedure is as follows: A call is placed by a facility. This prohibits any other facility from placing a call and turns on a busy light at all facilities. The recording system operator then checks the following: (1) proper facility plugboard, (2) amplifier gain settings, (3) proper starting block number, (4) correct reading number, and (5) handler loaded. When the operator has the equipment ready to record, he connects the facility to the transmission cable and indicates "ready," which means that control of equipment has been transferred to the facility. The facility begins its test and starts the recording system at the appropriate time. When the test is finished, the facility stops the recording system and is automatically dropped from the cable. Facility number, time of the recording, starting and ending block number, and indications of unusual phenomena are entered in a log at this time by the operator.

To assist the operator in detecting equipment faults and to aid the test engineer, a record monitoring mode of operation may be selected. In this mode the playback system monitors the recording in progress. The monitor provides a check on all recording equipment except the writing circuits, write heads, and tape handler. It also can provide a check on the transmission cable and transducers. Monitoring signals are presented to the playback equipment in the same format as they appear when playing back a tape. This is explained in greater detail in the DIGITAL PLAYBACK SYSTEM section of this chapter.

DIGITAL PLAYBACK SYSTEM

General Description

After the test data are recorded on magnetic tape, the reel of tape is rewound and moved to the digital playback system tape transport for inspection and editing. The playback equipment associated with the digital recording system is used for this purpose and is shown in figure III-11. Selected data inputs of a test are displayed as analog signals in an X-Y fashion or against time on oscillographic storage oscilloscope-type output equipment. Someone familiar with the test data may then pick out areas of interest for computing. These areas are identified by noting block number at the beginning and end of the interest area. The data area between the selected block numbers may then be entered into either an analog or digital computer for further processing.

Figure III-12 shows a simplified block diagram of the digital playback system. The recording method was a modified nonreturn-to-zero. A binary "1" from the playback tape transport head is indicated by a 15-millivolt pulse either positive or negative, depending upon the direction of flux reversal of the magnetic tape. A binary "0" is indicated by the absence of a pulse in a frame. Eight read amplifiers, one per tape track, amplify and transform these pulses into uniform rectangular pulses of one polarity.

The first operation of the playback must be to establish the identity of the frames, since three frames must be properly grouped to form a data word. This is accomplished by the Two-Time detector circuit that monitors track 8. This circuit detects when binary "1's" are recorded in two successive frames. This detection occurs coincident with frame 2 of every block and is used to establish word framing for the playback of the block of data.

The ancillary code information in track 8 is assembled in ancillary code shift registers. Neon lights connected to these registers visually indicate the reading number, facility, and so forth. The block number register information is used to identify the areas of interest of data. A visual display of information in this register is presented on the operator console, which is shown in figure III-13. When the equipment is running, the indicator lights of the block number register give the operator a continuous indication of position within a data reading. Upon stopping the equipment, the last read block number is displayed statically by the indicator lights.

In addition to the visual displays of all ancillary coding, the block number register is continually examined by two sets of AND gates, as shown in the block diagram in figure III-12. The first set of AND gates is labeled Select First Block, and the second set is labeled Select Last Block. Both sets of gates are controlled by a series of switches as pictured in the operator console photograph (fig. III-13). When coincidence occurs between the selected block number of one set of console switches and the number in the block number register, an output pulse from the selected AND gate is formed. When the system is operated in the forward direction, the First-Block Coincidence Pulse heralds the start of information flow to any one of the selected output devices to be discussed later. In forward mode the Last-Block Coincidence Pulse provides a system stop. In reverse-mode operation the First-Block Coincidence Pulse provides the stop command.

Tape tracks 1 to 7 are checked every frame for odd parity. If any of the three frames of a data word do not pass the parity check, a parity error signal is transmitted to the selected output device.

Located just above the frame parity checker in figure III-12 is the circuit block that forms clock pulses. The clock pulses are generated by OR gating the seven data tracks (tracks 1 to 7). Since a parity bit in track 7 is generated during recording so that the sum of bits in tracks 1 to 7 is always an odd number, this method produces a clock pulse for every frame of the data. Data-Word Clock Pulses are formed by dividing the clock pulses by three, using a ring-of-three shift register. This consists of three shift register stages in a closed ring such that the first loads the second, the second loads the third, and the third loads the first on each shift command. A binary "1" is circulated through the register with the clock pulses serving as the shift commands. By monitoring the third-stage output and detecting a binary "1" in this position, the Data-Word Clock Pulse is formed. The ring-of-three is preset to a standard condition by the Two-Time of the first block of data after a playback forward command. The Two-Time Pulse was described previously as the unit that established word framing.

At the beginning of every succeeding block of data the binary state of the three shift register cards is examined at Two-Time. If the ring-of-three conditions do not agree with the standard conditions established at the preceding Two-Time, a Word Framing Error Pulse is produced and the correct ring conditions are reestablished. The Word Framing Error Pulse thus indicates that the word framing has gone out of step somewhere within the previous block of data. This pulse notifies the output devices, which may then take the appropriate actions.

The data word register consists of 21 shift register stages. The register is loaded in three successive parallel loads of seven bits, each corresponding to the three frames of the data word. A Data-Word Clock Pulse indicates that a complete word of data has been entered into the data word register and serves as the register examine command.

The digital data word is now assembled in the data word register and may be transmitted to the digital computer. This will be discussed further in the following section entitled "Output Modes."

If the data are to be analog edited or prepared for analog computer entry, the complete data word is examined in two parts: the seven word number bits and the 11 data bits (fig. III-9). The seven word number bits are presented in parallel to five word select AND gates and are labeled "Select Word A" to "Select Word E," as shown in figure III-12. The gates are controlled by pushbutton switches located on the operator control console, which is shown in figure III-13. These gates are probed by Data-Word Clock Pulses. A Word Coincidence Pulse is produced when the word number bits in the data-word register are in coincidence with the word number selected for that gate.

The 11 data bits of selected words are transferred to a commercially available digital-to-analog converter. The output of this converter is an analog voltage that is proportional to the digital input. A Word Coincidence Pulse from any of the five-word select gates initiates the conversion. The data word, now in analog form, is presented in parallel to the five analog storage units. These units are of the same type as those described previously under the section entitled "Storage and Main Multiplexer." Each of the five storage units receives sample and store commands from its word select AND gate. Thus, a single selected word of data is presented as an analog voltage at the output of each of the analog storage units. The overall accuracy of the analog voltage at the output of the storage unit is within 0.25 percent of the digital word value. The output voltage range is ±10 volts.

Output Modes

Digital computer. - Since the primary function of the central transient recording system is the recording of data for machine computation, the primary output mode is connection to a digital computer. It is a high-speed, stored-program, general purpose computer, which at this writing is located approximately 3/5 mile from the playback equipment. The systems are connected by means of standard telephone-type underground cable. The transmitted pulses are 25 microseconds in width at the sending end and degrade to approximately 35 microseconds at the receiving end. A second digital playback system has been constructed and is used primarily with the digital computer. It is located in the same area as the computer.

The block diagram (fig. III-12) indicates the lines of communication to the computer in the digital computer output mode. The 21 bits of the data word register are transmitted along with the Data Word Clock Pulses for every word that is recorded. Since every word is transmitted when in digital computer mode, the word select gates are not used. The Two-Time Pulse is available so that the computer can maintain block reference for checking purposes. Both the Word Framing Error and the Frame Parity Error Pulses are transmitted. The original digital playback system does not present the ancillary information to the computer. The second playback system presents the ancillary code register information in parallel every block. This is used primarily for checking and verifying the tape positioning. A computer-initiated search for data from a particular facility has also been incorporated.

The actual operation of the equipment in the digital computer mode is usually preceded by one of the forms of quick-look editing to be described later. This allows the positioning of the tape to a point just before the start of the area of interest and keeps computing time to a minimum. Upon receipt of a forward read command from the digital computer, the playback system starts the tape in forward motion and begins a transmission of data after the first generated Two-Time Pulse. The data entry into the computer is under computer program control and enters into one of the input-output registers. At this point the data are again checked for parity. The original data word along with various check bits is placed into magnetic core storage. At present there are approximately 500 to 1000 words of core storage available for data word storage. After entry of a given number of blocks as determined by the core storage available, a stop command is transmitted to the playback system. The playback system continues to transmit the block of data in which the stop command was issued. A playback system stop is issued by the next Two-Time Pulse, which stops transmission of data and commands a tape stop.

After a system stop is commanded, the tape comes to rest well within the next block of data. Thus, it is necessary to reposition the tape by reversing one block after entry of each section of data into the digital computer. Approximately 20 milliseconds after the computer stop command has been executed, a reverse command is issued by playback system machine control, and a stop is executed at the next Two-Time Pulse. The playback system is now positioned for the next forward read. The complete cycle time is approximately 35 milliseconds. In this application the additional control time needed to reposition the tape is used by the computer as data processing time so that no real disadvantage in input time efficiency exists.

Analog computer. - The second output mode of the digital playback system is connection to a commercially available analog computer described in chapter IV. In this output mode the five selected channels of analog output from the digital system are transmitted by shielded cable to the analog computer patch board where they may be appropriately entered into the analog computer program. Contrary to the mode of operation with the digital computer, the analog computer is under the command of the digital playback system. The commands "start compute" and "stop compute" are derived from Select First Block and Select Last Block.

Storage oscilloscope. - The primary method of data editing before computation is with a storage-type oscilloscope. Several types of displays are available using this piece of readout equipment: (1) One to four selected data channels may be plotted against time in a single sweep. (2) Any data channel may be displayed against any other data channel in an X-Y plot. (3) All data words may be displayed at a fast recurring sweep to produce vertical bar graphs as the data vary. (4) All data words may be displayed during a slow single sweep.

The first display is useful in the initial editing of a recording to determine the location of the various areas of interest. For this operation, a channel is selected that will best describe the data event (e.g., chamber pressure in a rocket test). When the operator views an area of interest on the storage scope, he stops the system and logs the block number at this tape location. In this manner he develops the listing of block numbers that is used to position the tape in any of the other output modes. The operator may also enter a selected block number into the First-Block Select register and plot any channel against time. He may now reverse to the selected block number and overplot other data channels for comparison purposes. This allows a useful preliminary study of the data event after initial location of the area of interest. Superimposed plots of a rocket chamber pressure and downstream nozzle pressure against time over a 20-second interval shown in figure III-14 illustrate this type display.

The second display of the storage scope presents two channels of data in an X-Y plot. The main use of this is in preparation for output to an ink-type X-Y plotter.

In the third display every data word is converted to an analog voltage and connected to the Y deflection system of the storage scope. After allowing time for the vertical deflection system of the storage scope to stabilize, a display command intensity modulates the write beam. This plots a dot on the viewing screen for each word of data displayed. In this type of display, the sweep trigger pulse is derived from the Select Word A AND gate. The sweep speed is set to be fast enough to resolve adjacent words of data visually. Thus, a sweep is triggered for every block of data, and a new line of dots is displayed. In time, this succeeds in presenting a series of data channels, commencing with the word selected in Select Word A register, as vertical bars. Because of the limited size of the viewing screen, a practical maximum of 16 channels may be viewed at one time. A type (3) bar-graph plot of 10 data channels recorded during a rocket performance test is shown in figure III-15.

In the fourth display on the storage scope, a plot of all words is displayed using a slow single sweep. This display is the same as the first type except that all words are overplotted on one tape pass. The display is useful in identifying data traces only if the number of inputs recorded is small or the inputs of interest have very distinguishing characteristics. This mode will, however, indicate in one tape pass if some data channel is in gross error (e.g., very noisy, inverted, etc.). Another type display, usually type (3), would be used to identify the offending data channel. This type display of eight channels of temperature against time taken during a heat-transfer experiment over a 20-second interval is shown in figure III-16.

X-Y plotter. - The X-Y plotter output produces a 10- by 15-inch ink-type plot. The X input is taken from Analog Storage Word A. The Y input is taken from Analog Storage Word B for X-Y plots. If desired, the output of Storage Word B against time may be plotted. Display commands are available from the Select First and Select Last Block AND gates to control the operation of the plotter. This mode is used when the test engineer desires a permanent hard copy of a raw data plot for quick reference before computed data are available.

Recording oscillograph. - The recording oscillograph is able to display five selected data channels against time on a single tape pass. The use of this mode is similar to the X-Y plotter mode in that it is also used for quick reference to the unprocessed data.

Monitor recording. - As mentioned previously, the monitor recording mode is used to monitor the recording system and the data transducers. The playback tape handler is disengaged in this mode, and the playback system input signals are received from the record system. The storage scope is useful in viewing the input data channels for noise content, range, polarity, and so forth before the recording of the actual test. The first type display is used in most cases during the actual test recording.

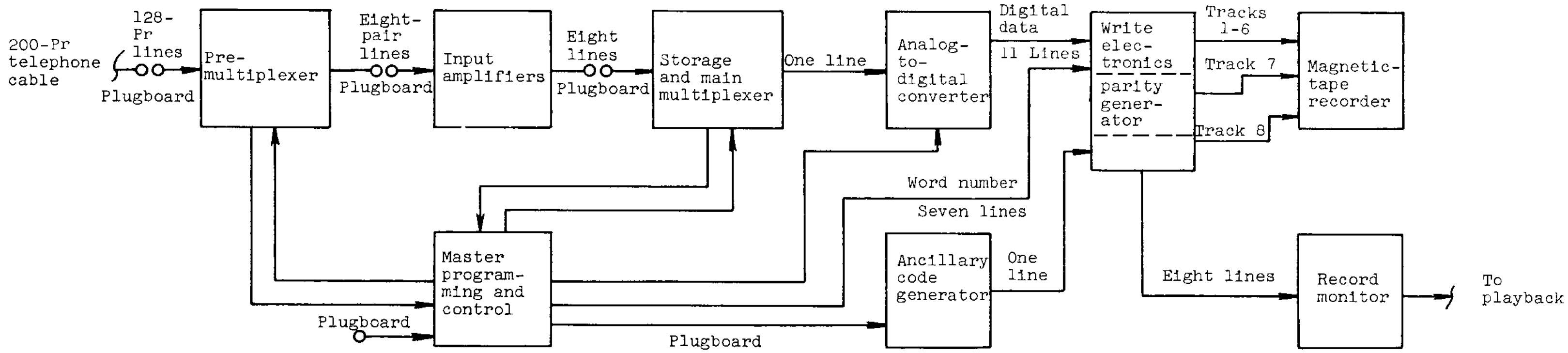


Figure III-1. - High-speed digital recording system block diagram.

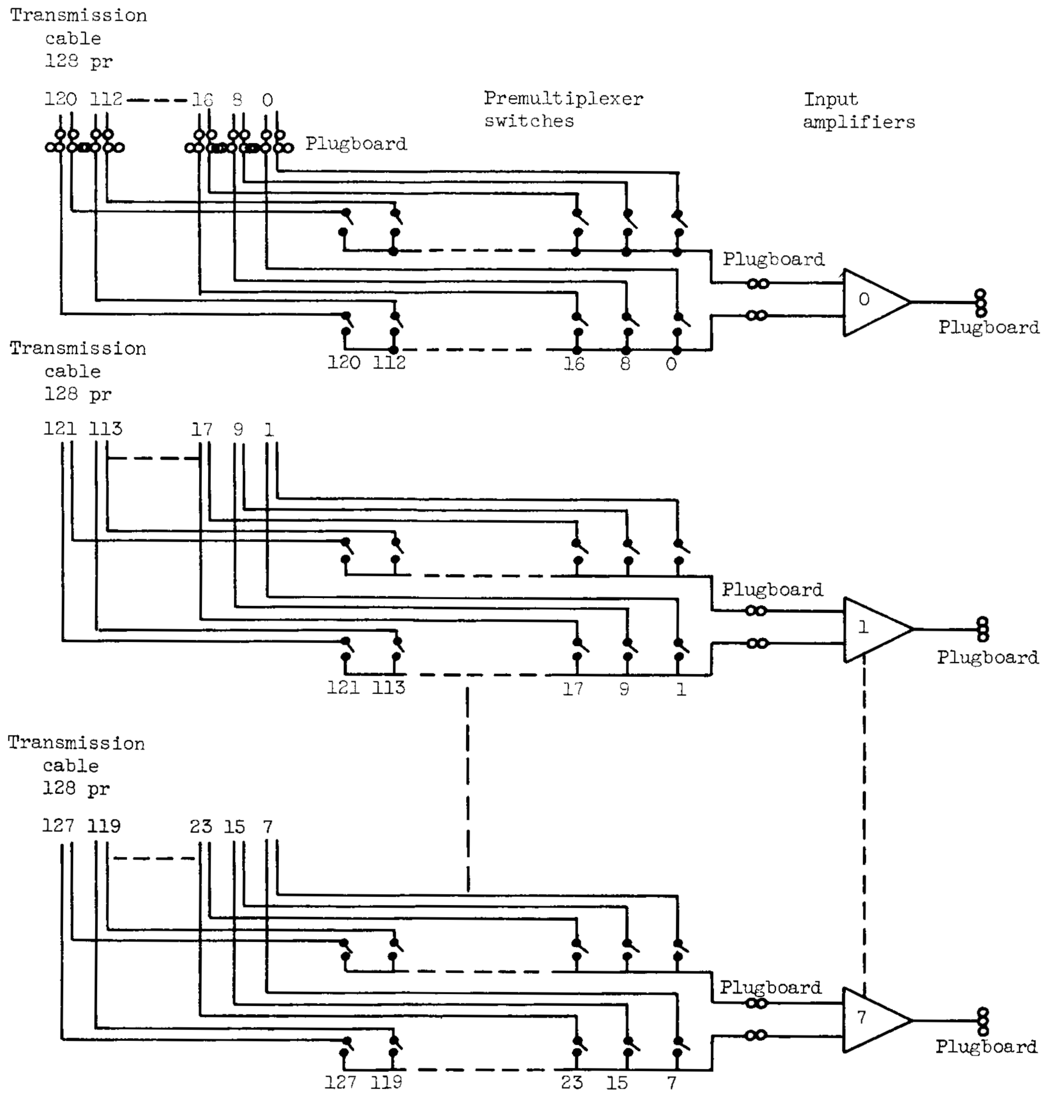


Figure III-2. - Premultiplexer switching scheme.

Switching sequence	
Sample	Switches actuated
1	0 - 7
2	8 - 15
3	16 - 23
4	24 - 31
5	32 - 39
6	40 - 47
7	48 - 55
8	56 - 63
9	64 - 71
10	72 - 79
11	80 - 87
12	88 - 95
13	96 - 103
14	104 - 111
15	112 - 119
16	120 - 127

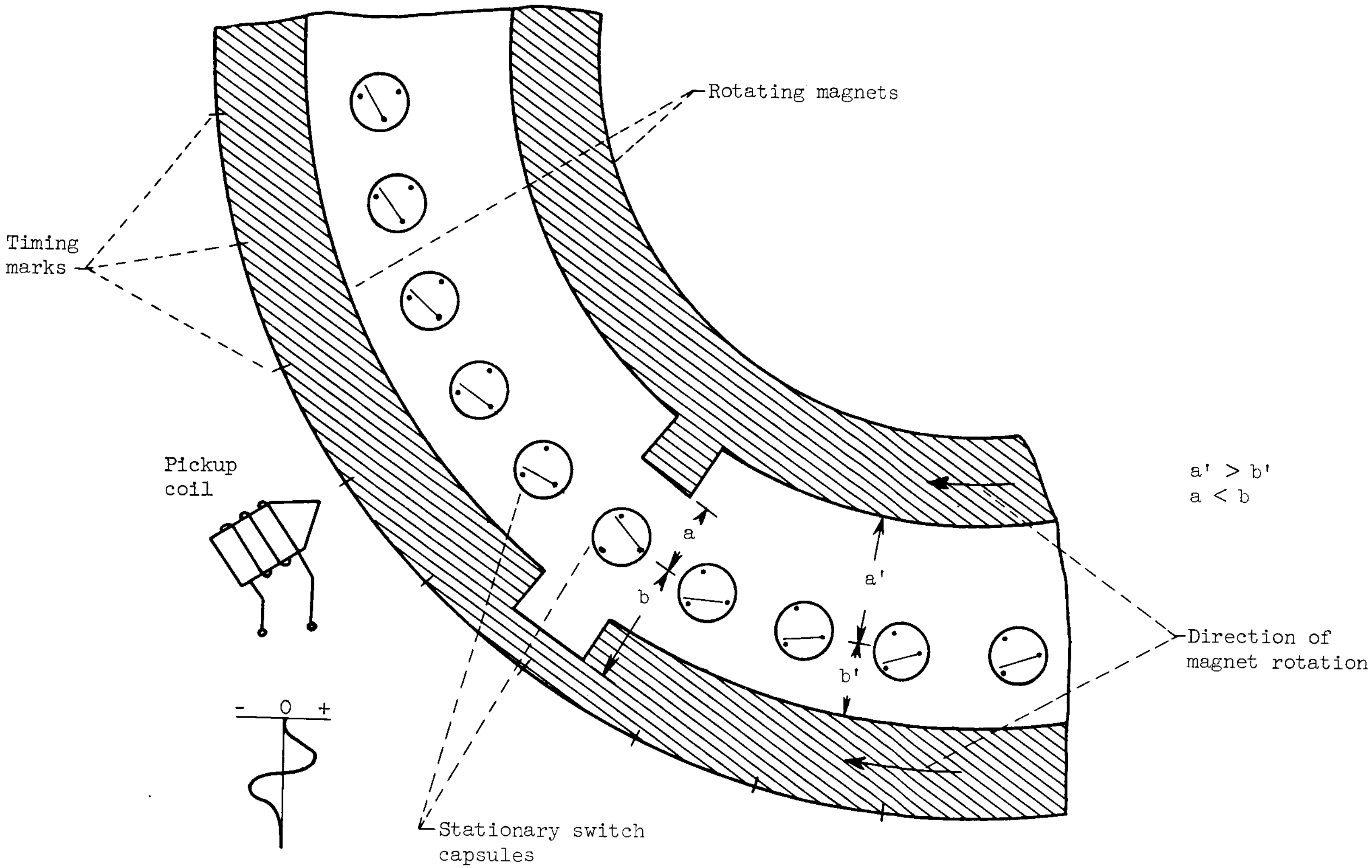


Figure III-3. - Mechanical premultiplexer detail.

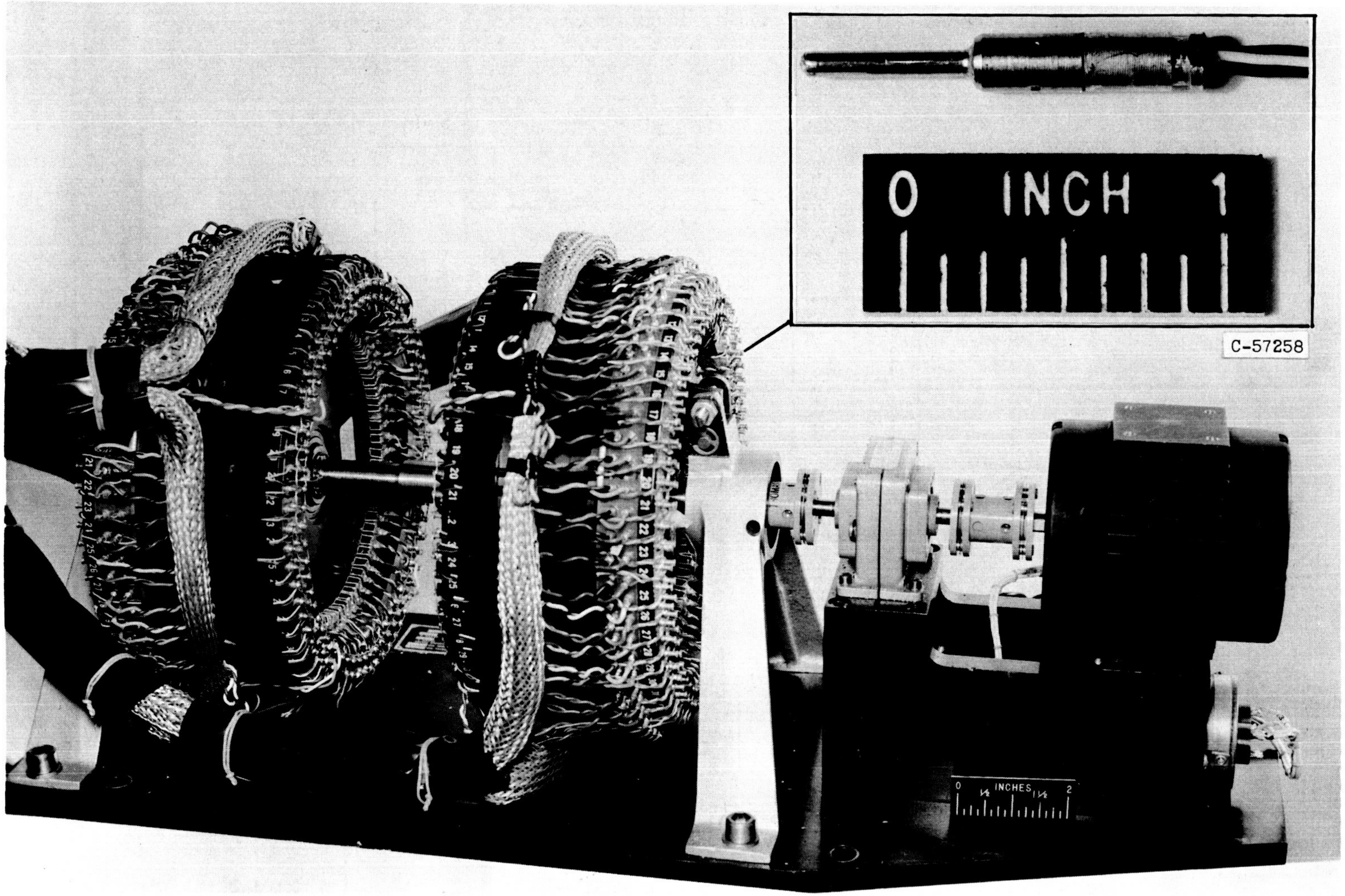
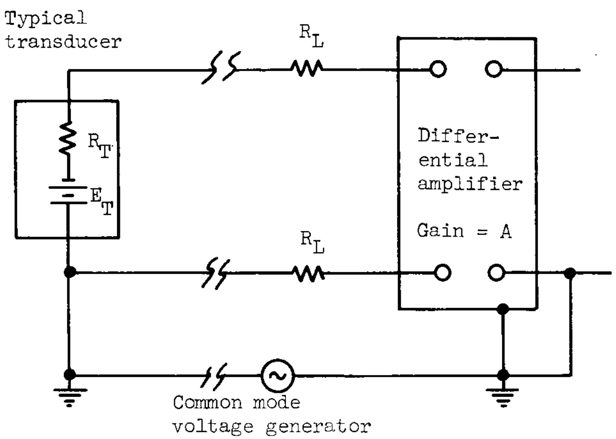
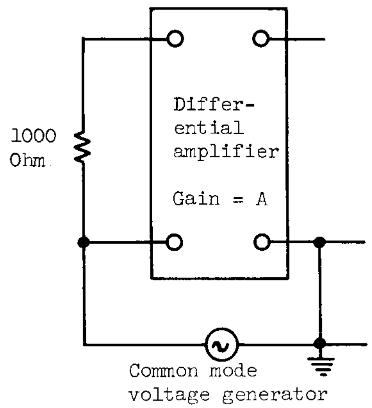


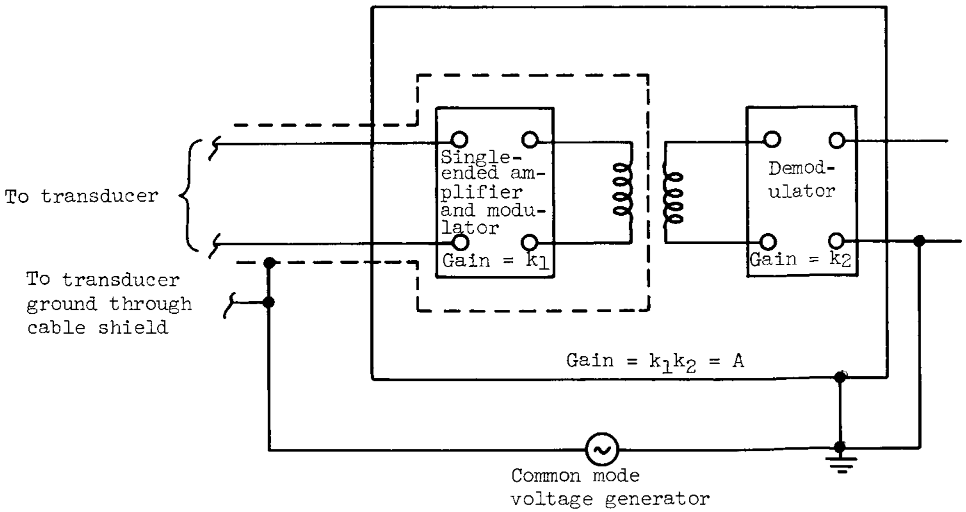
Figure III-4. - Mechanical premultiplexer.



(a) Common mode voltage in a typical test configuration.



(b) Test setup for measuring amplifier common mode rejection.



(c) An amplifier design that gives high common mode rejection.

Figure III-5. - Common mode voltage rejection in differential amplifiers.

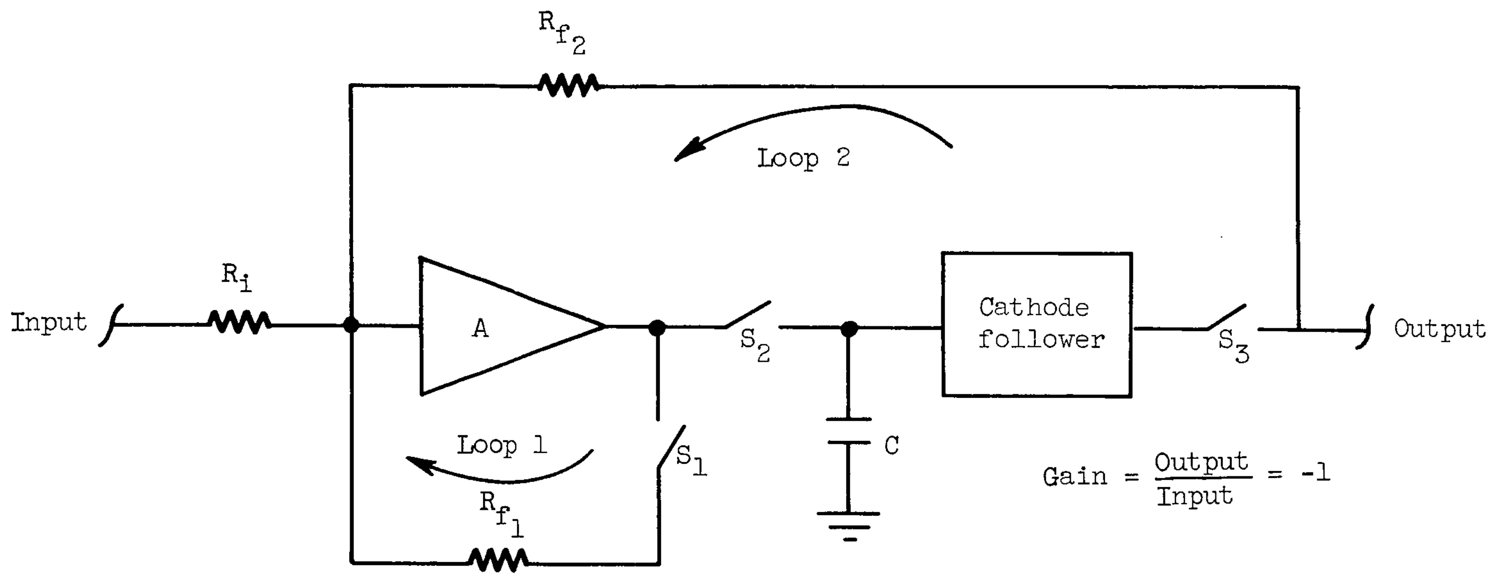


Figure III-6. - Storage and main multiplexer (eight units).

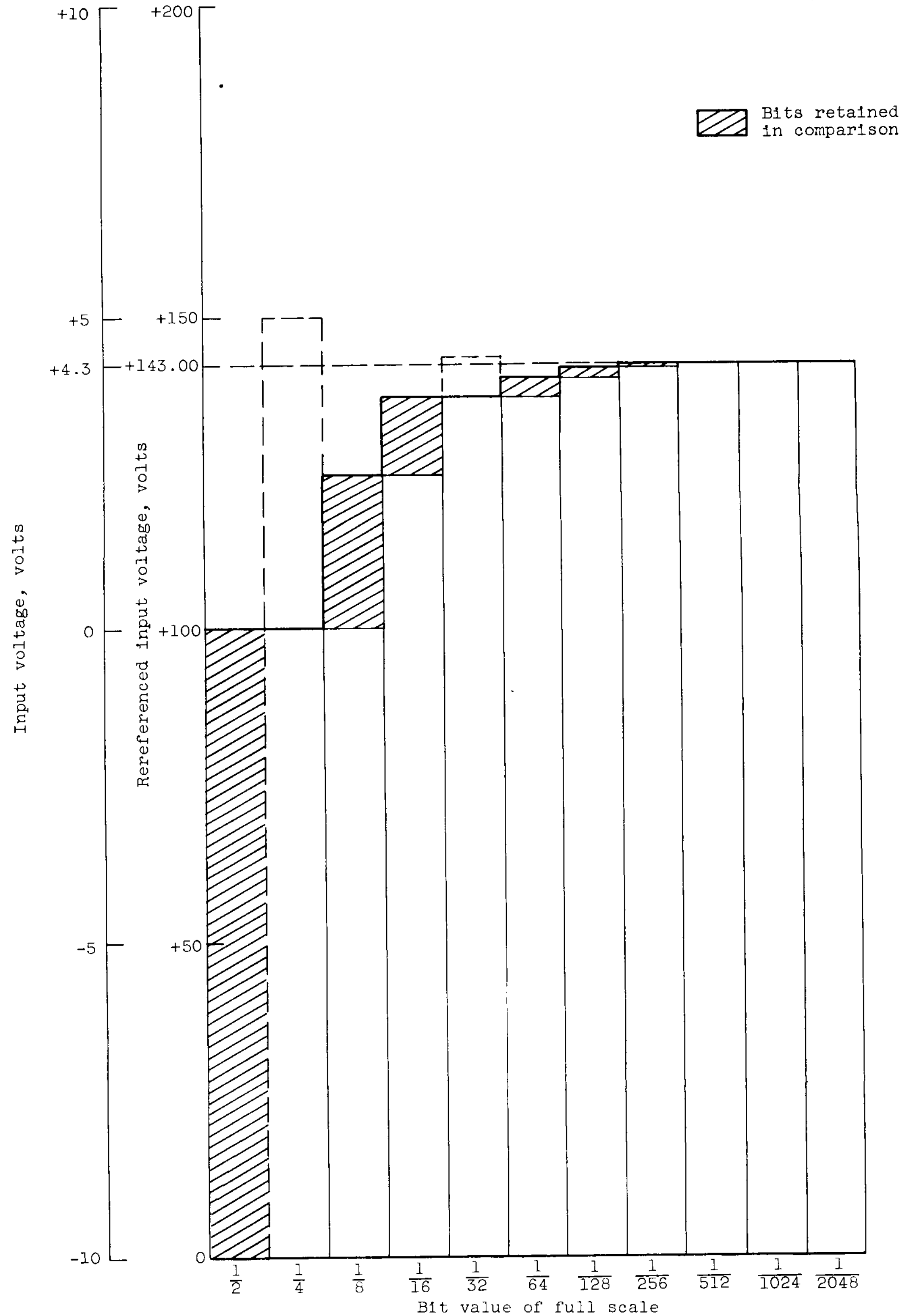


Figure III-7. - Analog-to-digital conversion successive approximation example.

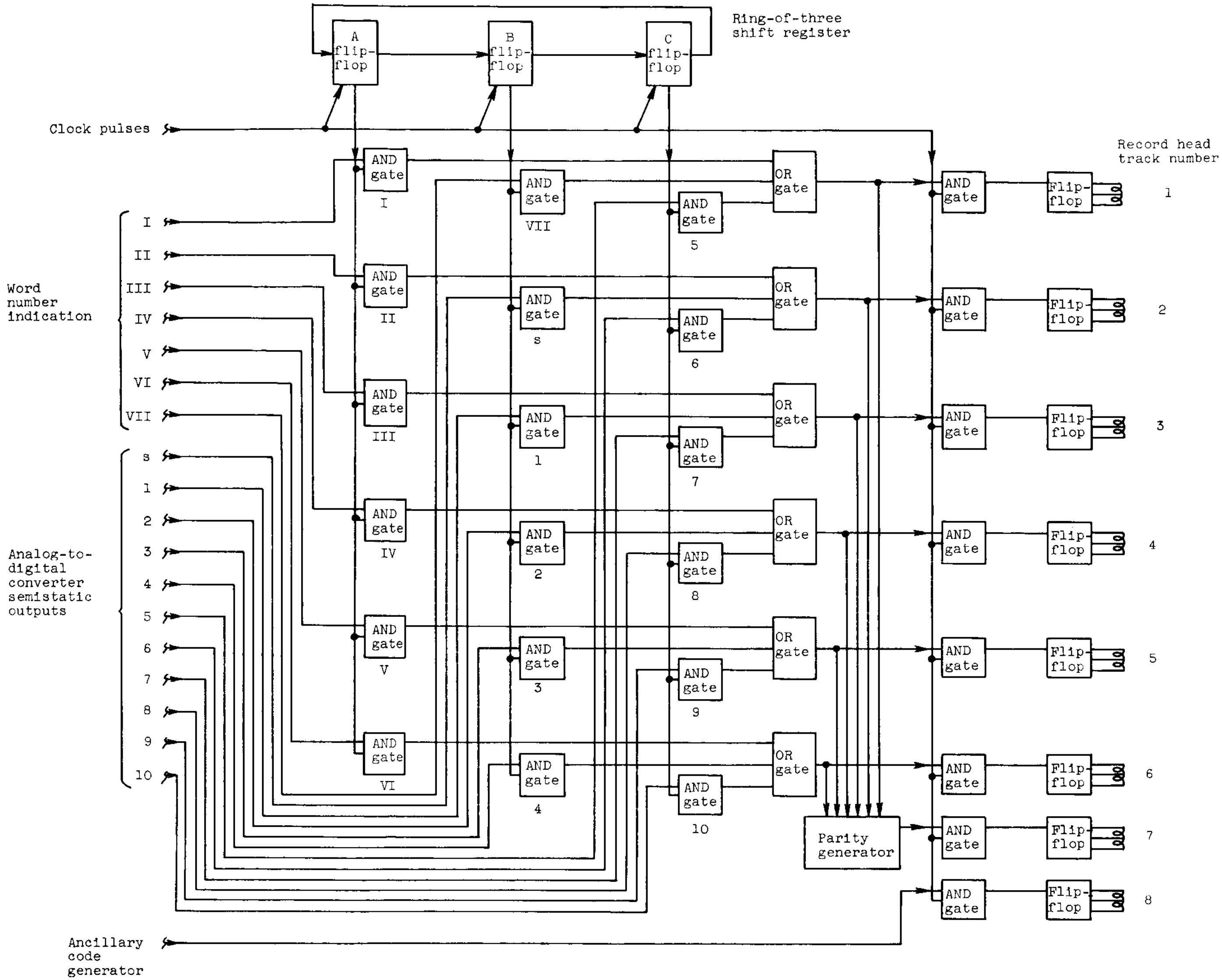


Figure III-8. - Digital recording write circuitry.

		Data word 1			Data word 2		
Track number	Frame	1	2	3	4	5	6
1		I	VII	5	I	VII	5
2		II	s	6	II	s	6
3		III	1	7	III	1	7
4		IV	2	8	IV	2	8
5		V	3	9	V	3	9
6		VI	4	10	VI	4	10
7		p	p	p	p	p	p
8		Ancillary coding			---	---	--

Tape motion ←

Data bit positions

s - Polarity
1 - Most significant bit
2
3
4
5
6
7
8
9
10 - Least significant bit

Word number bit positions

I - Most significant bit
II
III
IV
V
VI
VII - Least significant bit

p - Parity bit

Figure III-9. - Magnetic-tape format.

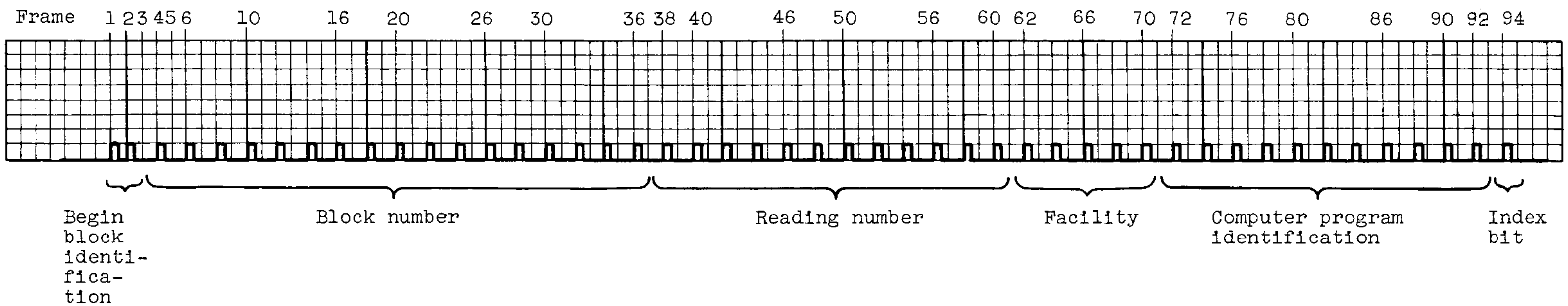


Figure III-10. - Coding in track 8.

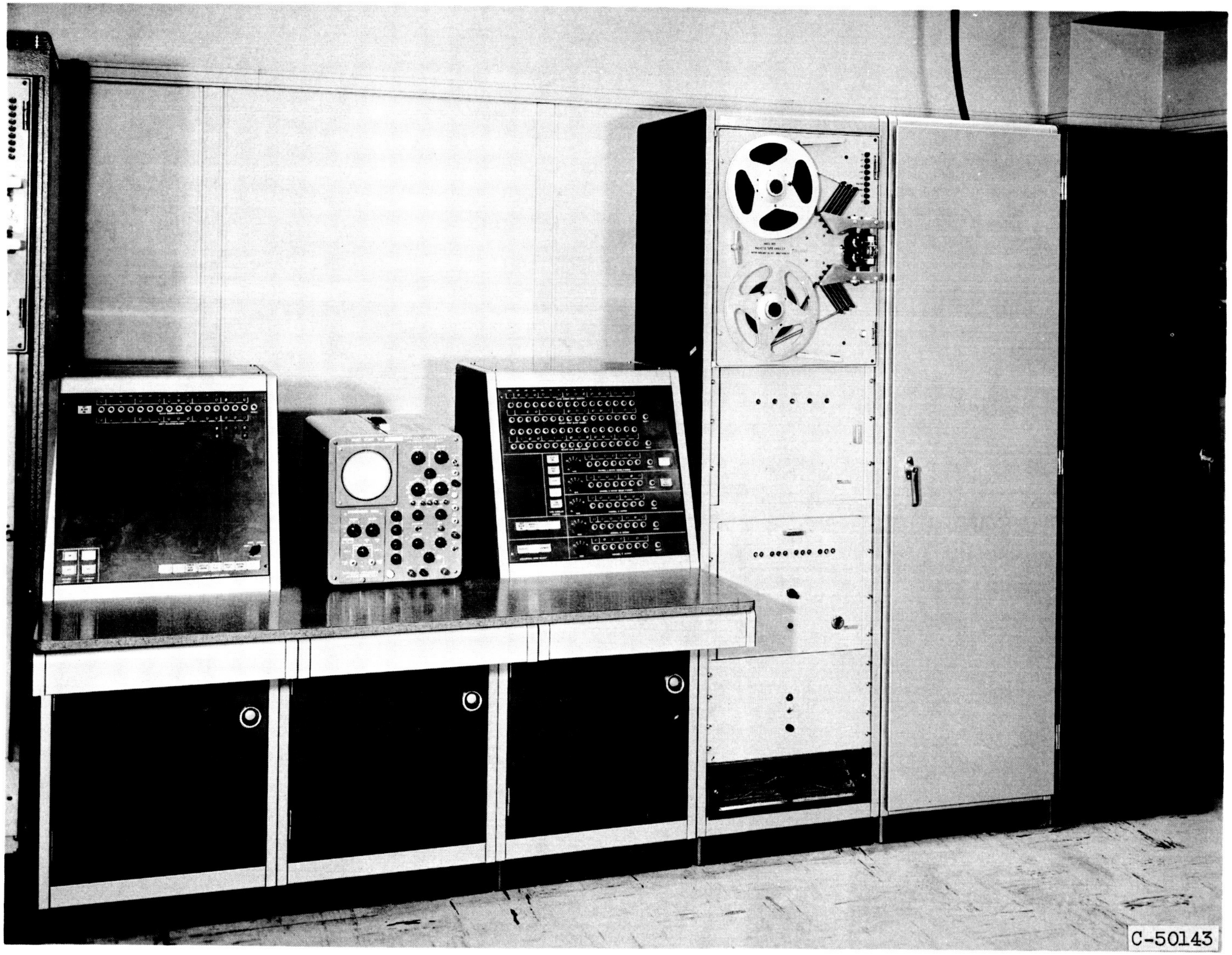


Figure III-11. - Digital playback system.

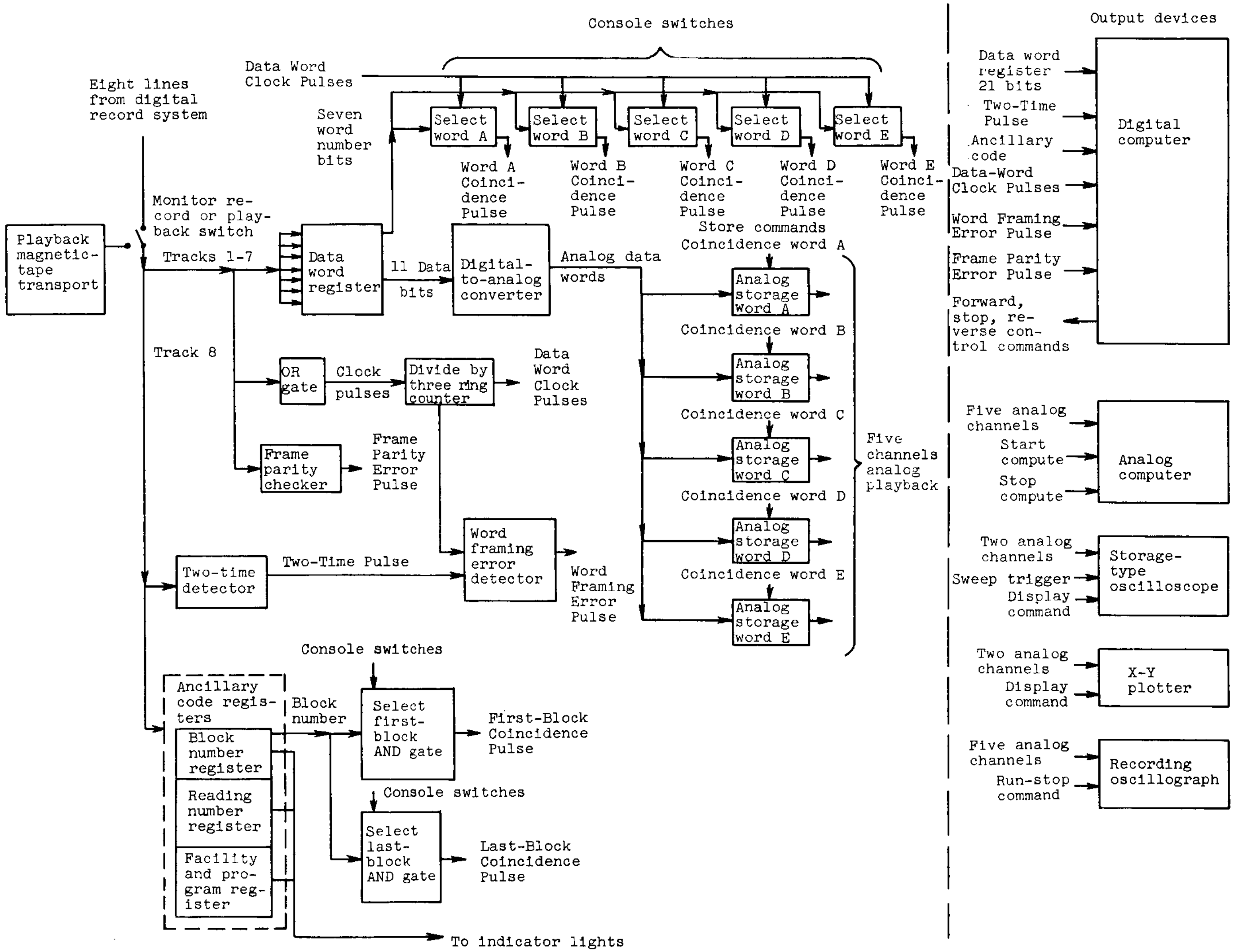


Figure III-12. - Block diagram playback digital system.

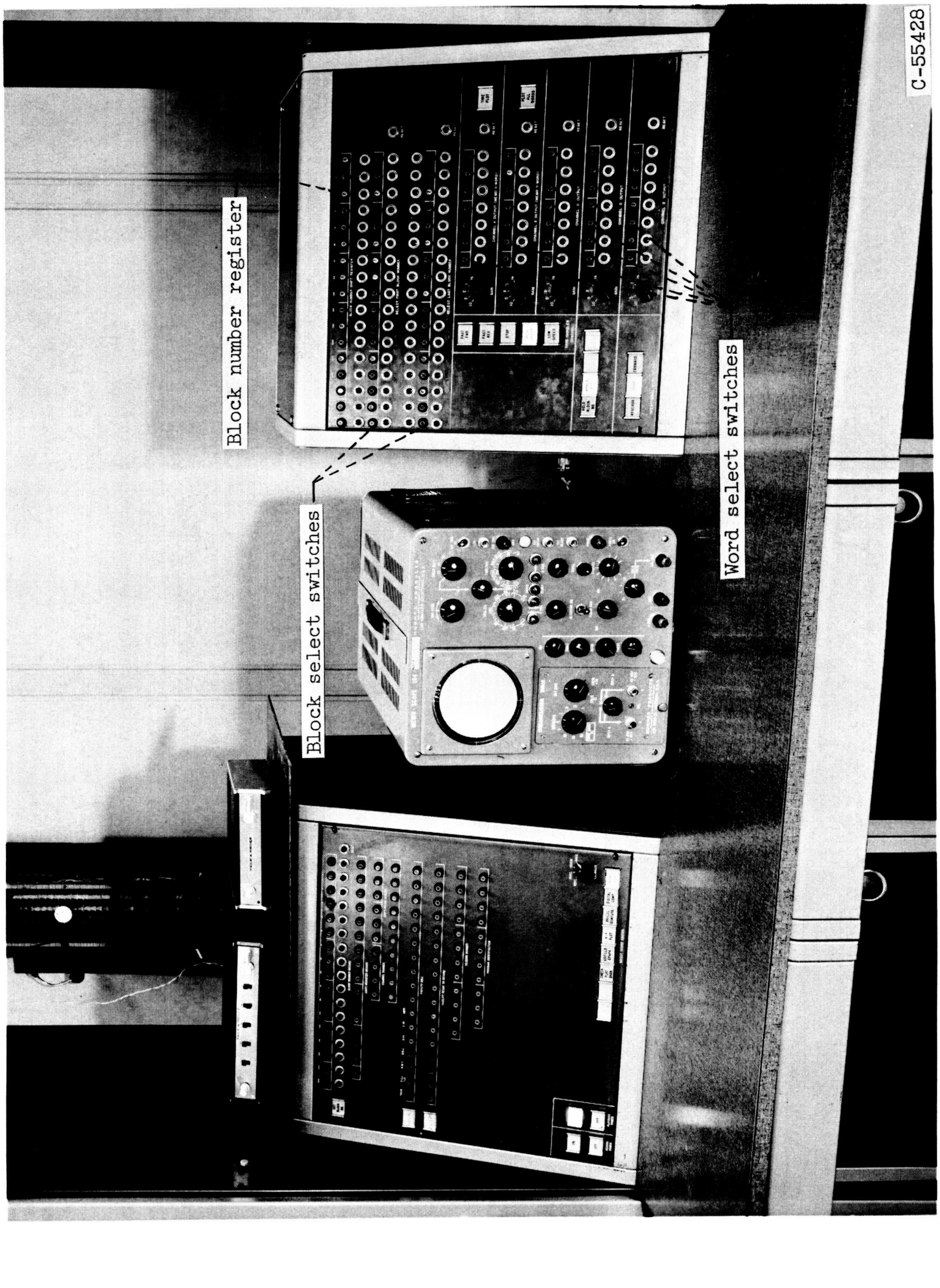


Figure III-13. - Digital control console.

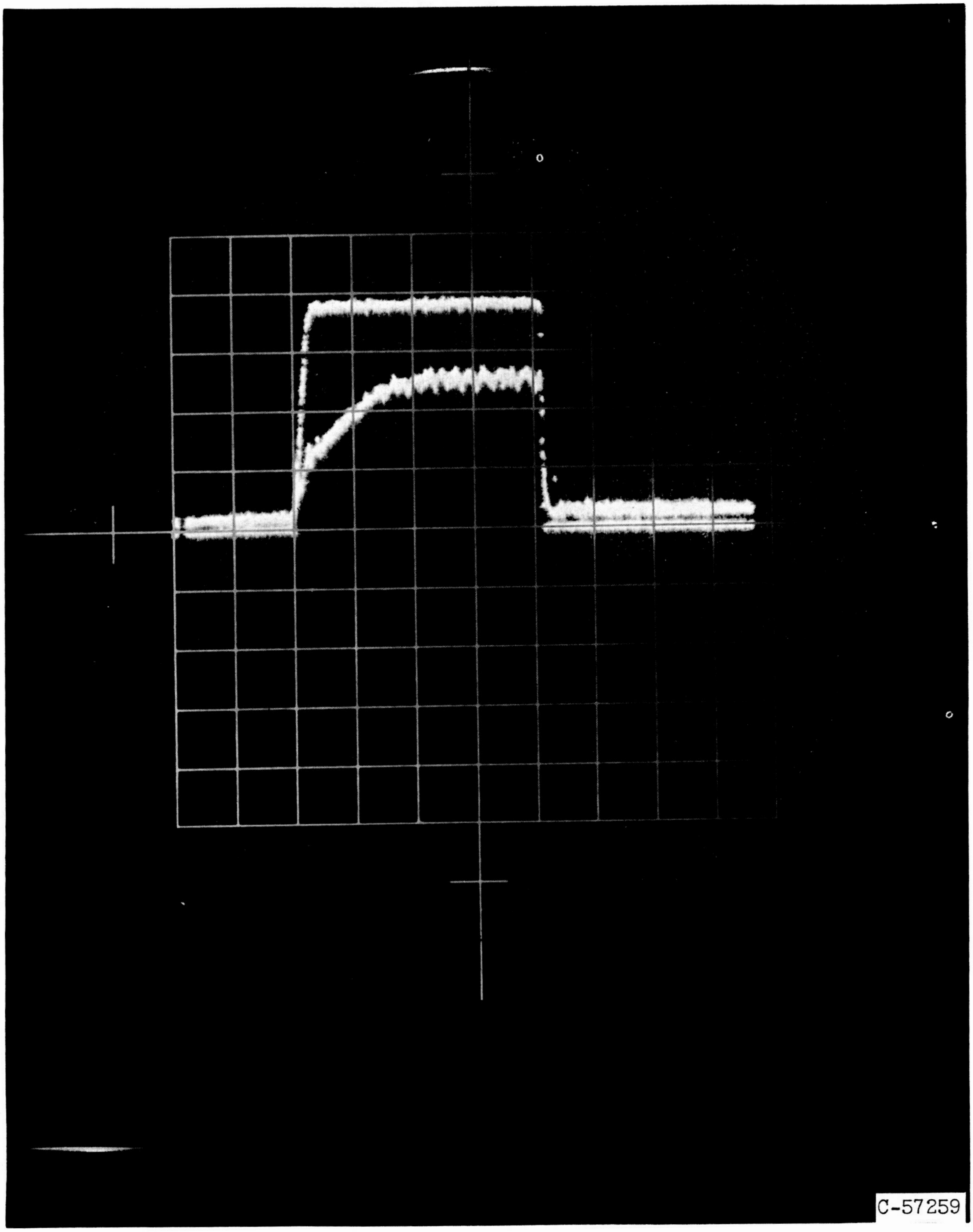


Figure III-14. - Storage oscilloscope display of rocket chamber pressure and nozzle pressure plotted against time.

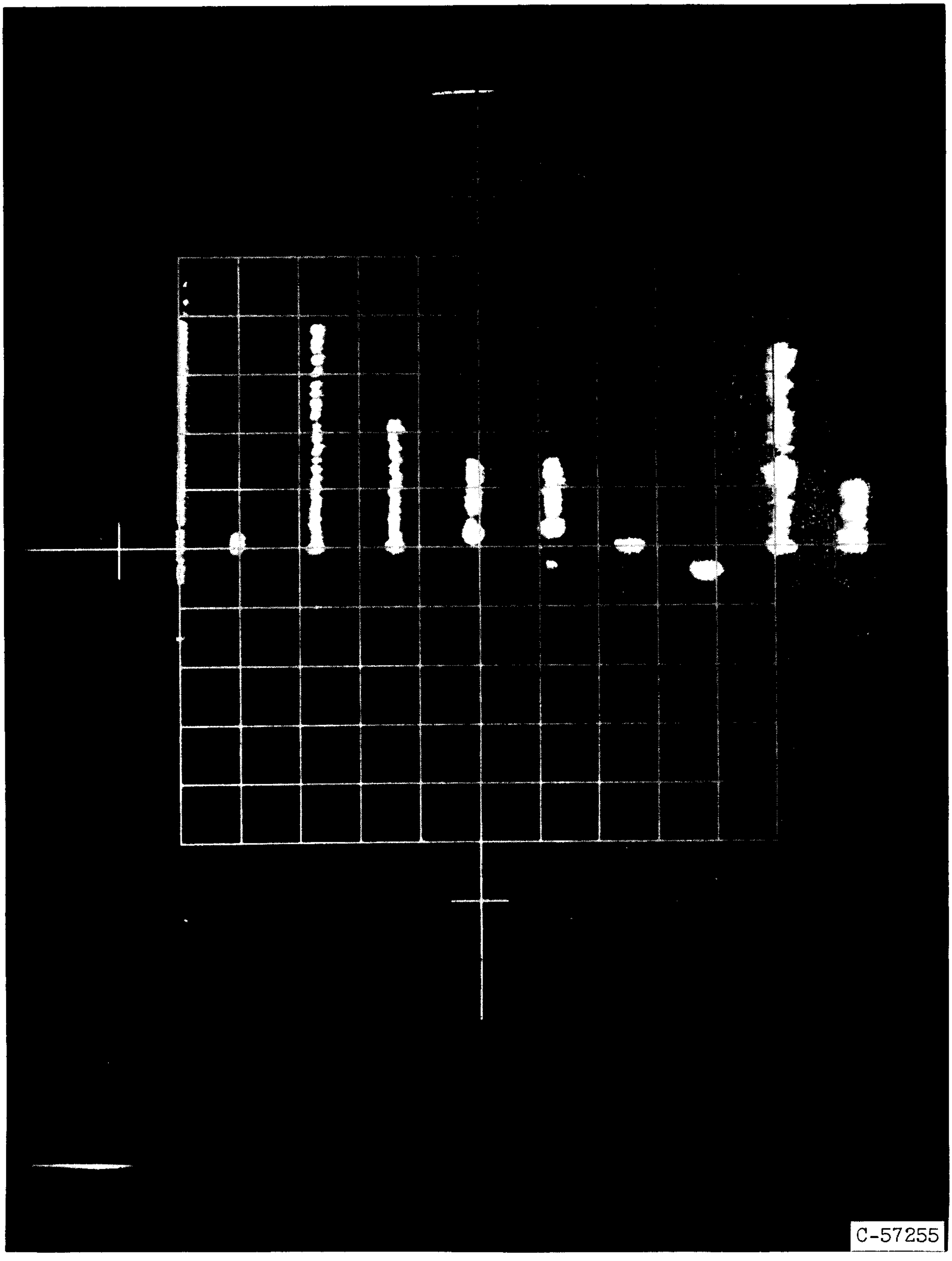


Figure III-15. - Bar-graph-type storage oscilloscope display.

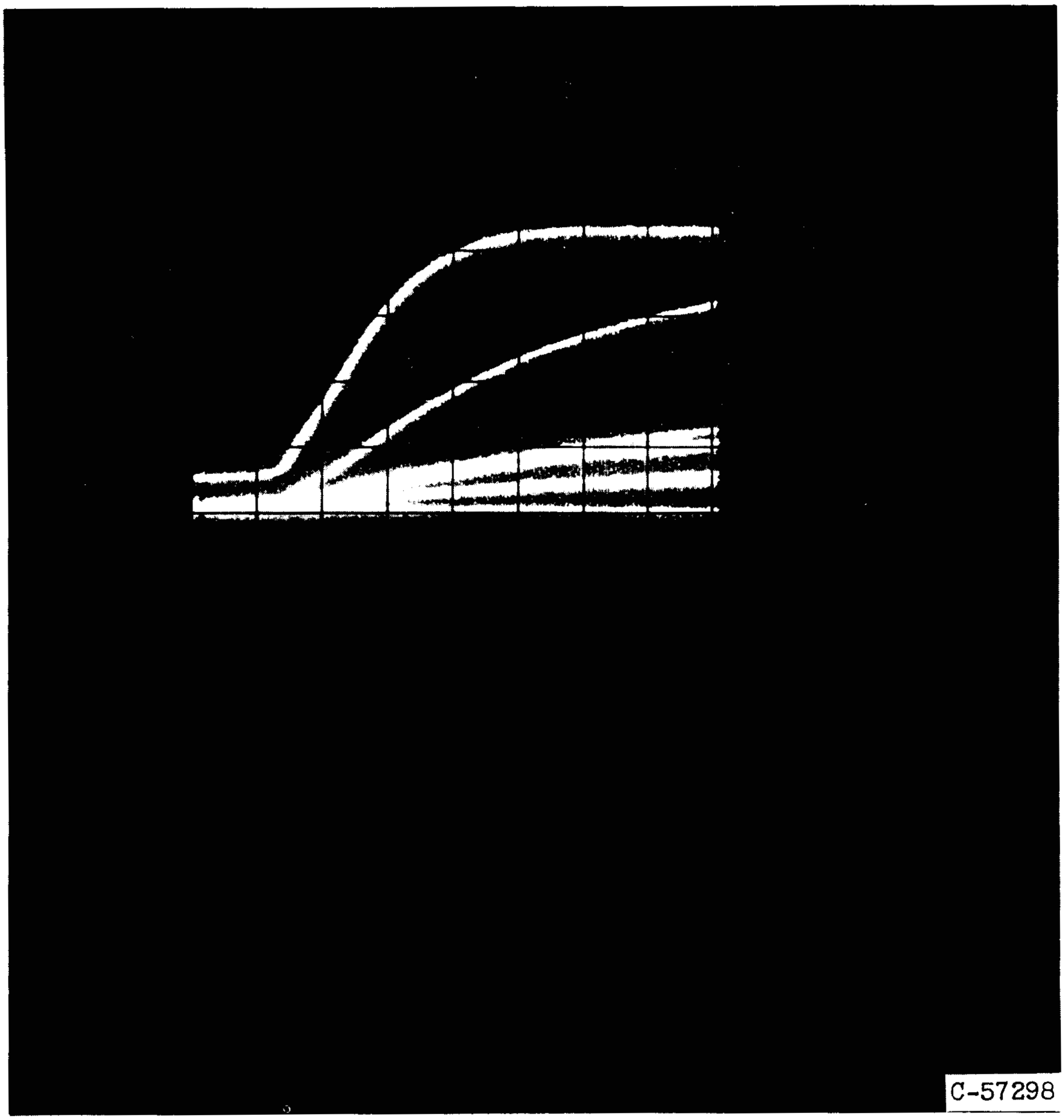


Figure III-16. - Storage oscilloscope display of heat-transfer data.

CHAPTER IV

ANALOG SYSTEM

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Richard N. Bell, John C. Sturman,
and Allen L. Perry

OVERALL SYSTEM DESCRIPTION

Introduction

The analog data system can be operated independently of the digital data system or concurrently with it. Its higher frequency response characteristics permit recording of data that cannot be recorded on the digital data system.

The analog system is made up of two 14-channel frequency-modulation-type recorders and their associated record and playback logic. In each of the two recorders, 12 channels are used for recording data, and two channels are used to record identification and calibration information. The two recorders can be used together to record 24 data channels from one facility or independently to record 12 data channels from each of two different facilities simultaneously.

Frequency response of the system is d.c. to 10 kilocycles. Input signal levels are ±10, ±20, ±50, ±100, ±500, and ±1000 millivolts full scale. Accuracy to which a d-c voltage can be recorded and played back is 1 percent of full-scale voltage.

Information can be played back at 1/2, 1/4, 1/8, 1/16, and 1/32 of normal recording speed in addition to normal recording speed. By using this feature, high-frequency signals may be recorded on the analog system, played back at a fraction of the recording speed, and re-recorded on the digital system for digital processing of high-frequency information.

Block Diagram and System Description

The portion of figure IV-1 within the dashed lines shows one of the two frequency-modulation recorders and its associated record and playback logic. Unamplified transducer signals are sent from the facilities over special data cables, described in chapter II. At each facility the data lines are connected to the transducers through line relays, which are operated from the central data room.

At the central data room the data lines are terminated on the input plugboard cradle. The input plugboard connects the selected data lines through a data/calibration switch to the data record electronics. This switch connects either the data lines or calibration voltages to the inputs of the record electronics. The calibration voltages are recorded at zero and full-scale values. A timer (described in detail later) controls the direct-current switch action.

The recording system is controlled from each facility by means of a control panel or an electromechanical programmer at the facility. The control panel contains monitoring lights and switches for controlling the recording system during the time that the facility is taking data. The panel lights indicate the state of the recording system, while the switches provide a means for starting and stopping the recording equipment. Control from the programmer is also provided. In this case the panel control switches are not used, although the panel lights still indicate the state of the recording system.

Control signals are sent over a control cable (independent of the data cables), which is also used for telephone and intercommunication and for the playback of data to facilities. Playback may be of either raw data or analog computer outputs from "on-line" computations made during the test run. At the facility, the playback can be used for monitoring or (in case of "on-line" computations) for immediate test evaluation.

At the central data room, output devices for data playback are: storage oscilloscope for quick look, analog computer for processing both analog and digital recorded data, and X-Y plotters and strip chart oscillograph for plotting both raw and processed data.

The output plugboard is used to connect the analog system output to the selected output devices, amplifiers (if required to raise the playback electronics output levels), and the automatic drift corrector. The automatic drift corrector uses recorded calibration information to correct automatically, during playback, for drift in the record electronics that may have occurred between initial setup and recording.

During recording, record and block numbers are encoded on one of the two control tracks by means of the record and block number encoder. This information is used during playback to search for any desired reading and any area of data within a reading. The search is accomplished by means of the control track decoder, record and block number decoder, record and block number register, and record and block number storage.

Tape Format

The analog transient recording system uses a 1-inch-wide, 14-track, staggered head. The tracks (see fig. IV-2) are 0.050 inch wide and are on 0.070-inch centers. Of the 14 tracks available, 12 tracks are used for data recording, giving a capacity of 12 data channels, while two tracks are used for playback systems control.

The technique of frequency modulation is used in recording data in the 12 data tracks, referred to as data channels 0 to 11 in figure IV-2. The signal recorded on tape is a frequency that is proportional to the amplitude of the data signal. The use of frequency modulation enables recording and reproducing d-c signals and also permits playing back a recording at a much slower speed than the recording speed without degradation of the signal. Figure IV-3 shows the relation of the recorded frequency against the input voltage amplitude of the data signal.

The control tracks are referred to as channels A and B in figure IV-2, and information recorded in those channels will be described in detail.

Zone Description

During a data run the tape record is divided into seven zones. The zone designation significance is as follows (see fig. IV-4):

Zone 1, record number. - Within the first zone on tape, a four-digit binary-coded decimal number is encoded serially on control channel A. The first two digits of the record number identify the facility for that particular run, and the last two digits identify the analog reading number. The time duration of the record number zone is 2 seconds.

Zone 2, zero calibrate. - This is a 3-second zone during which time the transducers are disconnected from the 12 data channels, and the data channel inputs are shorted. The data channels therefore record a frequency on tape corresponding to a zero voltage input. This is used during playback (see section entitled Automatic Drift Correction) to compensate for a long-term frequency drift of the record electronics.

Zone 3, full-scale calibrate. - This is a 3-second zone during which time the transducers are removed from the 12 data channels, and the data channel inputs are connected to an accurate full-scale voltage source. The calibration source is a 1.40-volt voltage standard for high-level-input conditions or the divided output of a high-gain differential amplifier with the appropriate full-scale input voltage for low-level-input conditions. The data channels therefore record a frequency on tape corresponding to a full-scale voltage input. This also is used during playback to compensate for the long-term frequency drift of the record electronics.

Zone 4, predata (nonusable data). - The time duration of zone 4 is either 2 seconds or 150 milliseconds long, depending upon the mode of operation. In the "manual" mode of operation the system is controlled by the facility operator through the use of the control panel. In this mode of operation the tape handler comes to a complete stop at the end of zone 3, and the transducers are reconnected to the data channel inputs. After receiving a "take-data" command signal from the test facility, a 2-second predata zone is then used to allow the tape handler to reach a constant speed. In the programmed mode of operation, the system is controlled by the programmer at the facility. In this mode of operation, the tape handler does not stop after zone 3, but goes directly into a 150-millisecond predata zone, during which time the transducers are reconnected to the data channel inputs. The predata zone is used to prevent either nonlinear tape motion during "manual" mode of operation or transients from input switching during "programmed" mode of operation from affecting the actual data field.

Zone 5, record data (usable data). - During this zone, whose time duration is determined solely by the test facility, the transducers are connected to the data channel inputs, and the data are recorded on the data channels. Also during this zone block numbers (described in detail later) are being recorded serially on control channel A, and a 54-kilocycle is recorded on control channel B. The block numbers are used to mark the tape for playback search, and the 54-kilocycle signal is used for wow and flutter compensation during playback. The termination of this zone is caused by a "stop" command from the test facility.

Zone 6, zero check. - Zone 6 is a $1\frac{1}{2}$- second zone that is the same as zone 2 (zero calibrate) except for the time duration. Zone 6 is compared with zone 2 during playback to verify that there was negligible frequency drift during the data run. For the normal data run, 2 minutes or less, the short-term frequency drift is less than 0.05 percent.

Zone 7, full-scale check. - Zone 7 is a $1\frac{1}{2}$-second zone that is the same as zone 3 (full-scale calibrate) except for the time duration. This zone is included so that verification can be made of negligible frequency drift during the data run.

Zone Definition

Each of the seven zones is defined by a unique combination of two of the three possible frequencies on control channels A and B. The zone time durations and code definitions are shown in figure IV-4. The (-)

corresponds to a fixed frequency of 32.4, the (0) to 54, and the (+) to 75.6 kilocycles. There are nine possible code combinations, seven of which are recorded on tape for zone identification. Of the remaining two, the (0)/(0) is not recorded on tape but is used during playback for blank tape indication, and the (-)/(-) is not used. The zone time duration and frequencies shown in figure IV-4 are for a tape speed of 60 inches per second.

Record Number

The record number (see fig. IV-5) is recorded on control channel A during the center portion of the record number zone. It is a four-digit binary-coded decimal number that indicates both the facility identification number and the analog reading number. The record number is encoded in such a manner that a frequency train 500 microseconds in time duration represents a binary "1" and a frequency train 250 microseconds in time duration represents a binary "0" with a bit leading-edge separation of 2 milliseconds. With a recording speed of 60 inches per second the bit area is 75.6 kilocycles, and the area between bits is 54 kilocycles.

The record number to be recorded is stored in the record number storage unit which is interrogated once at the beginning of each data run. The record number storage unit consists of a relay storage unit (decimal), a relay code conversion matrix (decimal to binary-coded decimal), and a visual display unit. The initial record number is manually entered into one of four available storage units and is held for use in either the analog or digital transient recording system. The facility identification number (first two digits of the record number) identifies one of the four available storage units as being reserved for a specific test facility. After the completion of the data run the reading number (last two digits of the record number) of the associated test facility is automatically advanced; thus, each data run is identified by a unique record number. The visual display units are used to indicate the contents of the record number storage unit for operator log entry.

Block Number

The block number (see fig. IV-6) is recorded on control channel A during the record data zone. It is a four-digit binary-coded decimal number and is encoded on tape between "marker" pulses spaced 50 milliseconds apart. The marker pulse is encoded as a frequency train 1500 microseconds in time duration. The block number is encoded in such a manner that a frequency train 500 microseconds in time duration represents a binary "0" and a frequency train 250 microseconds in time duration represents a binary "1" with a bit leading-edge separation of 2 milliseconds. The leading edge of the highest order bit of the block number is separated from the leading edge of the "marker" pulse by 10 milliseconds. In the block number the bit area is 54 kilocycles, and the area between the bits is 75.6 kilocycles.

The block number is stored in a binary-coded decimal counter contained in the record number/block number generator and has a total capacity of 10,000 digits (from 0000 to 9999). The block number counter is initialized to zero prior to each data run and is advanced one count every 50 milliseconds during the time data are being recorded. This permits a data run of 8-1/3 minutes (at 60 in./sec) before the block number counter overflows. This exceeds the anticipated time requirement for any data run.

Figures IV-4, IV-5, and IV-6 are shown for a tape speed of 60 inches per second. For 30-inch-per-second operation the time durations are increased by a factor of 2, and the frequencies are decreased by a factor of 2 so that the format is compatible at all playback speeds.

Timer and Record Number/Block Number Generator

The timer is an electronic unit utilizing digital logic techniques for controlling the operation of the analog transient recording system and for controlling the various time zones into which the tape record is divided. The timer also generates the fixed frequencies used in identifying these zones.

A serial control technique, using cascaded monostable multivibrators, was chosen for use in the timer. This method was chosen because, since a high degree of accuracy is not required in the time duration of the zones, its flexibility (zone time durations can be changed without additional equipment or modification of existing equipment) and ease in troubleshooting make it preferable..

Counter control technique consists of using an astable multivibrator and dividing the output frequency by the use of a string of binary scalers to achieve the desired time interval. Because the counter control technique is a very accurate means of generating time intervals, it is used in the record number/block number generator to determine the pulse widths of the encoded number.

The logic elements used are transistorized units designed and built at Lewis Research Center.

Prior to using the analog transient recording system for recording data an automatic check is performed on the following units: timer, record number/block number generator, tape, tape transport, plugboards, recording speed, and record number storage unit. If each of these check correctly (each has its own panel light on the control console), the system "ready" light, also on the control console, will indicate that the system is ready to accept a data run.

When the test facility initiates a "call" (see fig. IV-7) for the analog transient recording system, the control unit starts the tape handler and the timer. The timer, in conjunction with the control unit and record number/block number generator, allows the tape handler to get up to speed, encodes a record number (zone 1), and places the precalibration (zones 2 and 3) on tape. Then, depending upon the mode of operation, the system will, in the "manual" mode, stop in a ready-to-record state or, in the "programmed" mode, go through a 150-millisecond predata zone (zone 4) directly into the record data zone (zone 5). In "manual" mode of operation the system remains in a ready-to-record status until the test facility sends a "take data" command to the system. The timer, which again controls the system through the control unit, starts the tape handler, and after a 2-second predata zone (zone 4) causes the system to go into the record data zone (zone 5). Once the system is in the record data zone, regardless of mode of operation, the record number/block number generator places a block number on tape every 50 milliseconds. At the completion of the data run, the test facility sends a "stop" command to the system. The timer then places, through the control unit, the post-calibration on tape (zone 6 and 7) and stops the system. A set of panel lights on the control console gives a visual indication of the timer and, hence, the system at all times.

Analog Computer

The analog computer, which is part of the central transient data facility, is a commercially available analog computer. It consists of 36 operational amplifiers (12 integrator-summers and 24 summers), eight electronic multipliers, 60 servo-set coefficient potentiometers, and six servo-set function generators. These components have nominally 0.1-percent accuracy with the exception of the function generators, which have 1.0-percent accuracy. A photograph of this computer is shown in figure I-4.

The analog computer is used to make on-line rocket-engine performance calculations while the rocket engine is being tested. These on-line calculations help the rocket test engineer to roughly assess the test results and speed up testing by eliminating the need for manual calculations during testing. Typical calculations of this type made on the analog computer are fuel and oxidant flow rates, oxidant-fuel ratio characteristic velocity, and specific impulse. More accurate calculations are also performed by a digital computer and are made available to the test engineer at a later time.

The analog computer is used at times in preference to the digital computer where analog plots of computed results during a complete test are more useful than digital tabulations, and when digital accuracy is not required in the results.

PLAYBACK FEATURES

The information from channels A and B is used during playback for the following purposes:

(1) Control the search logic during a record number and block number search

(2) Operate the automatic drift correction unit for automatic calibration on playback

(3) Correct for wow and flutter

The section entitled "Tape Format" explained what information is recorded in the two control channels A and B. The following sections will explain how the information in these control channels is decoded and used.

Control Channel Decoder

Identification of eight discrete zones has to be obtained from the control channels. The function of the control channel decoder is to determine which of these zones is being examined at any time during playback. These zones are:

(1) Record number zone

(2) Zero calibration zone

(3) Full-scale calibration zone

(4) Predata zone

(5) Data zone

(6) Zero check zone

(7) Full-scale check zone

(8) Blank tape

During playback, the frequency recorded on tape in the two control channels converted to a d-c voltage by an FM demodulator. The possible voltages are +1.4, 0, or -1.4 volts. Figure IV-8 shows the output voltages of each control channel demodulator during the eight zones. The output of each control channel demodulator is fed into a complementary amplifier. The amplifier has two output channels, each output channel having a voltage level of 0 or -5 volts. Both output channels can be zero volt at the same time, but they can never be at -5 volts at the same time. Figure IV-8 shows the output voltage of each channel of the amplifier when one of the three possible input voltages is applied to the amplifier input.

The decoder consists of AND gates combined so that an output is obtained on only one of eight separate output lines corresponding to the eight different zones. The truth table in figure IV-8 shows the inputs required by the AND logic from the four complementary amplifier outputs.

As soon as either the record number zone or the data zone is detected, the output lines of the other seven zones are disabled. The lines remain disabled until the end of either one of these two zones is reached. This ensures that no false output will be detected by the decoder during these two zones. Figure IV-8 shows why a false zone indication would be detected during the record number and data zones if this feature were not incorporated. As the record number bits appear, the output voltages of the two control channel demodulators are the same as the voltages obtained during the predata zone. When the block number bits appear, the two demodulator output voltages are the same as the voltages obtained during the blank tape zone.

All eight outputs are disabled when the tape transport is started and remain disabled for 3 seconds to allow the tape transport to get up to speed.

Record number and block number decoder. - The record and block number decoder is used for interpreting the pulses that make up the record numbers, block numbers, and also the marker pulses between block numbers. The leading edge of each pulse coming from control channel A is used to trigger a one-shot multivibrator which produces a standard length pulse. Pulses coming from this channel are compared with these standard length pulses. If the pulse from this channel is shorter than the standard, it is a "zero," and, if longer, it is a "one." After identification, each "zero" or "one" is loaded serially through a gate into the record and block number shift register. When the complete number has been entered into the register, the gate at the input is closed, and the number in the register is then compared with the number in storage.

The marker pulses between block numbers are used to reset the register and reopen the gate at the input. A "pseudo" marker pulse is generated between reading numbers when the system is searching for a reading number. The system is able to search in either the forward or reverse direction. In the forward direction the most significant bit of the reading or block number is read off tape first, while in the reverse direction the least significant bit is read off first. The register can be loaded from either end and shifted in either direction so that the bits will always be in the correct order in the register, regardless of the direction of search.

Comparator. - The record and block number storage comparator compares the numbers in storage when the analog data system is operating in the search mode. Its function is to indicate whether the number in storage is larger, smaller, or coincident with a number read from tape. This is done by comparing information in the register labeled "record and block number tape register" and "record and block number storage register" in figure IV-1.

The comparison is made in sequential steps, each of which compares a given bit of the number in the tape register with the corresponding bit of the number in the storage register. The comparison begins with the most significant bits of the numbers and progresses in a descending sequential manner, through the intermediate stages, to the last stage, which compares the least significant bits and yields an output if the numbers are coincident. If the numbers are not coincident, comparison progresses only until coindidence is lost, at which time a "too large" or "too small" output signal is generated.

A single stage of the comparator is shown in figure IV-9, and the complete comparator is shown in figure IV-10. Besides the previously mentioned register inputs, each stage must receive a command signal to operate. The command signal to the first stage is supplied from the record block number decoder and enables the first stage to deliver a signal that is indicative of the tape register and storage register inputs in the most significant bit position. Should a "1" exist in the storage register and a "0" appear in the register tape, a "too small" signal occurs; conversely, a "0" in the storage register and a "1" in the tape register result in a "too large" output. These signals terminate at controls that determine the direction of the tape handler and are treated in detail elsewhere in this report. Whenever the bit on the tape register is identical to the corresponding bit in the storage register, a coincidence signal is produced. This internally generated signal becomes the command for the second stage. Coincidence output from the second stage, indicating coincidence in both first and second stages, creates the command for the third, and so on to the last stage where the coincidence signal becomes the coincidence input to the tape search controls.

Tape Search Controls

The record number and block numbers recorded on tape are used during playback to locate any desired reading from a specific facility and any desired section of the data within that reading. The record number consists of a two-digit reading number and a two-digit facility number, and is written on tape in the record number zone. The block number is a four-digit number written at 50-millisecond intervals during the time data are being recorded in each reading. The desired section of data in each reading is played into X-Y plotters, strip-chart recorders, or an analog computer for computations and plotting.

The tape search controls use signals from the comparator to determine if the direction of search is correct or if the direction of search has to be reversed. In searching, the reel motors do the driving rather than the capstan, thus making it possible to initiate either a forward or reverse search. The search speed is 60 inches per second.

The record number and block number search controls can be operated in either one of two playback modes. The modes are:

(1) Manual playback. This mode is used primarily for editing. The operator must choose whether a search is to be made for record number or block number. After making the search, the tape transport will stop at a point immediately ahead of the selected record or block number.

(2) Automatic playback. This mode is used after the data have been edited and are being played back for computations and plotting. In this mode, the tape transport switches into capstan drive after the record number has been found. Then, as the zero and full-scale calibration zones are passed through, the output of the playback electronics is automatically adjusted to correct for any drift that may have occurred in the record and playback electronics. The transport continues running, and, when the first stored block number is reached, the coincidence pulse received at this time starts the analog computer or any other selected output device. The transport continues in drive until the last stored block number is reached, at which time the coincidence pulse stops the computer, tape transport, and other output devices.

The ability to hold a block number in display is a feature of the search controls that can be used in either the manual or automatic playback modes. The block number that is in the register or being loaded into the register can be held in the register and displayed by pressing the "hold block number" button. When the button is released, the numbers will continue to run through the register. Another feature of the search controls that is used primarily for editing is the ability to stop the transport and hold the last block number in display.

Automatic Drift Correction

The analog record modulators have a long-term drift associated with them. To increase the overall accuracy of the system, the outputs of the playback system are automatically adjusted during playback of each record, using the recorded calibration signals. Figure IV-11 shows the drift correction circuitry for one data channel. During the zero calibration zone, the voltage at point 1 is compared in the servoamplifier with ground. The error signal (the sum of the demodulator output voltage and the voltage at the wiper arm of potentiometer B) is used to operate the servomotor that drives the wiper arm of potentiometer B until point 1 is at zero volt. During the full-scale zone, the voltage at point 1 is compared with an accurate +1.4 volts by the servoamplifier. The error signal (the demodulator output voltage plus the zero offset voltage) operates the servomotor, which drives the wiper arm of potentiometer A until point 1 is at +1.4 volts. A single servoamplifier is switched between the two servomotors. Signals from the control decoder are used to switch the motors and the standard voltages at the proper time.

If the output of the demodulator were below +1.4 volts, it would be impossible to balance out the full-scale voltage. In order to ensure that this situation does not occur, the output of the playback demodulator is adjusted to give 1.55 volts at full scale instead of 1.4 volts.

The automatic drift correction circuit can correct for a maximum of +5 percent zero drift and a -5 percent full-scale drift at the same time. Checks of drift of record modulators show that the maximum drift correction is far above the amount that can be expected. Over a 48-hour period, with the record modulators being adjusted only at the beginning of the period, the zero drift was 1.8 percent and the full-scale drift was 2.1 percent. In actual operation the modulators are adjusted every 8 hours.

Analog Quick-Look System

The analog quick-look system provides for a visual display of any desired portion of the data recorded by the analog recording system. It fulfills the dual function of providing immediate visual review of the recorded data after a run and editing of the tape prior to processing the data. The system is composed of two separate parts: a storage-type oscilloscope capable of indefinite image retention and an input multiplexer. The latter makes it possible to display from one to 12 channels of data simultaneously, which the oscilloscope can store for detailed study if desired.

Storage Oscilloscope

The storage oscilloscope is a commercially available instrument. It can be used as a conventional oscilloscope or in the storage mode to provide indefinite storage. Other than the storage property, the features that suit it to this use are a reasonably fast rise time and slow sweep rates. The fast rise time allows the use of a 30-kilocycle sampling rate in the multiplexer. This sampling rate then limits the frequency response of each channel to approximately 1 kilocycle when displaying six channels simultaneously. A slow sweep rate is desirable so that long records of data can be displayed at one time. Since many tests, such as rocket firings, are of short duration, it is in some cases possible to display a complete run on one sweep. If long-time storage is not desired, it is possible to adjust the oscilloscope to provide just long enough persistence for a good display at slow but repetitive sweeps. In this way one can visually monitor long data runs to determine areas of specific interest quickly.

Multiplexer

It is the function of the multiplexer to time-sample multiple channels of data and sequentially feed them into a single output for display on the storage oscilloscope. A simplified block diagram of the multiplexer is shown in figure IV-12. The multiplexer receives 12 inputs from each of the output plugboards of the two analog recorders, this being their maximum capacity.

Standard modes of operation display all 12 channels from a single recorder simultaneously, or the first six or last six simultaneously. Any single channel can be observed directly by bypassing the multiplexer. Other readout combinations can be obtained by jumpering different combinations of inputs at the analog system output plugboard.

Relay A or B selects the inputs from one recorder or the other. Each of the 12 inputs selected goes to a step attenuator. When it is desired to observe a single channel, the signal is selected directly from the attenuator by a 12-position rotary switch and is fed to the storage oscilloscope. For multiple inputs the attenuator outputs feed individual amplifiers. These amplifiers perform the function of isolation as well as d-c level changing to permit individual vertical positioning of the oscilloscope trace. In this way it is possible to display six separate inputs on six distinct base lines displaced vertically on the oscilloscope screen.

Outputs from the 12 amplifiers go to level gates, each of which has three inputs. One input is the analog signal from the amplifier, and the other two are for logical control signals. Functionally the gates are AND gates that require a signal at each of the two logic inputs for the gate to pass the analog signal level at the third input.

For the case of six inputs, six of the gates have logic inputs from a gating flip-flop and the other six are cut off. The second logic input is from a ring-of-six counter that enables each of the six gates in sequence. In this way, six of the channels are gated to the output sequentially, and the sequence is repeated indefinitely. To display 12 inputs a trigger pulse is derived from the ring counter for each six inputs and is used to change the state of the gating flip-flop. Its output therefore gates first one group of six gates and then the other, alternately. The gating flip-flop is also used to produce a synchronizing pulse every second time it changes state. This can be used to trigger the oscilloscope sweep each time one full cycle of 12 inputs has been displayed. In this way successive scans of the 12 input channels will fall in the same horizontal position on the oscilloscope, producing a bar-graph type of display. If the synchronizing pulse were not used, it would be possible to use a slow sweep rate and display 12 chopped channels. However, since the signals usually overlap, 12 channels are in most cases too many for clarity.

The complete quick-look system can be seen in the center of the control console of figure I-5. All controls are directly beneath the storage oscilloscope.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, June 5, 1962

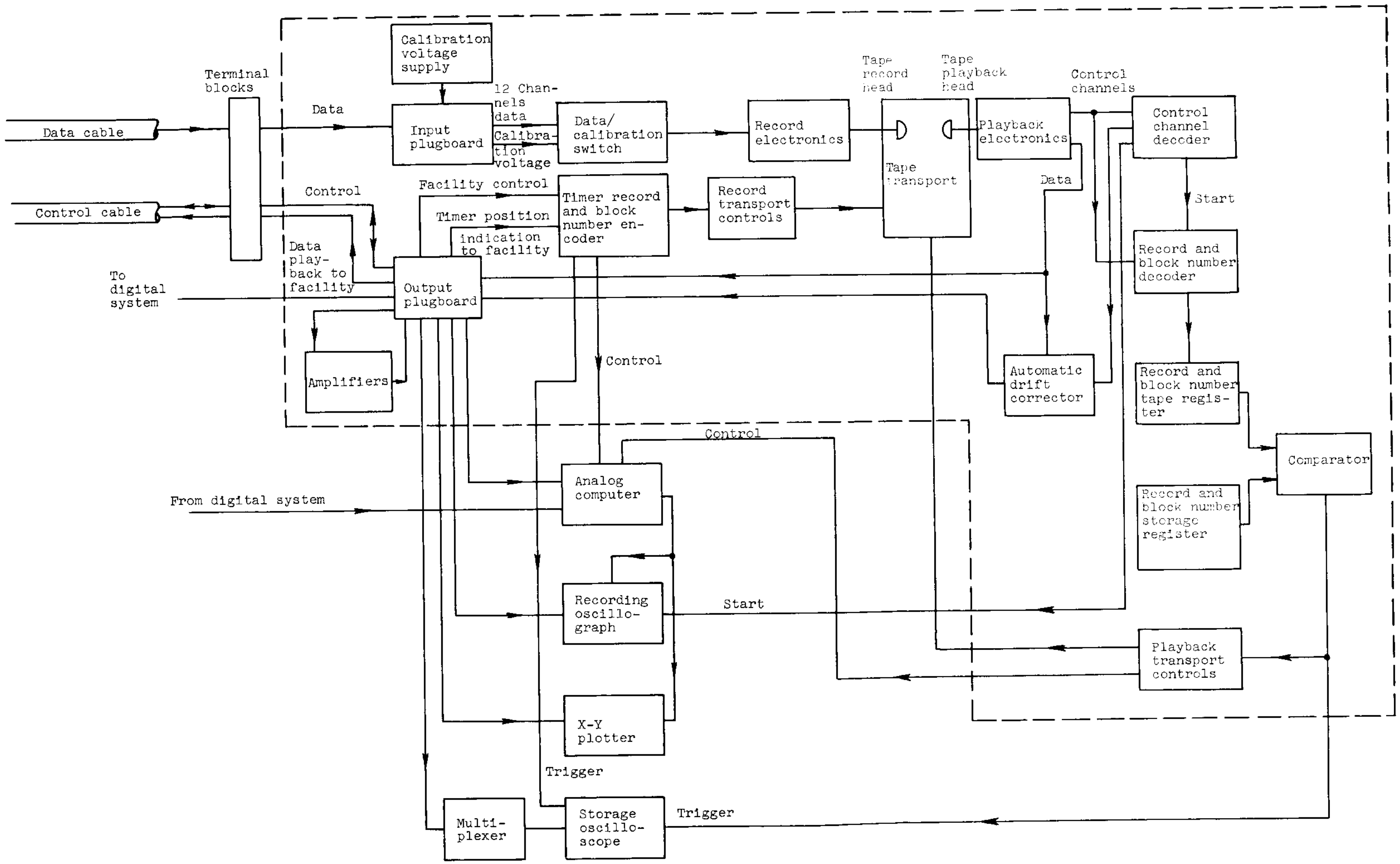


Figure IV-1. - Analog system block diagram.

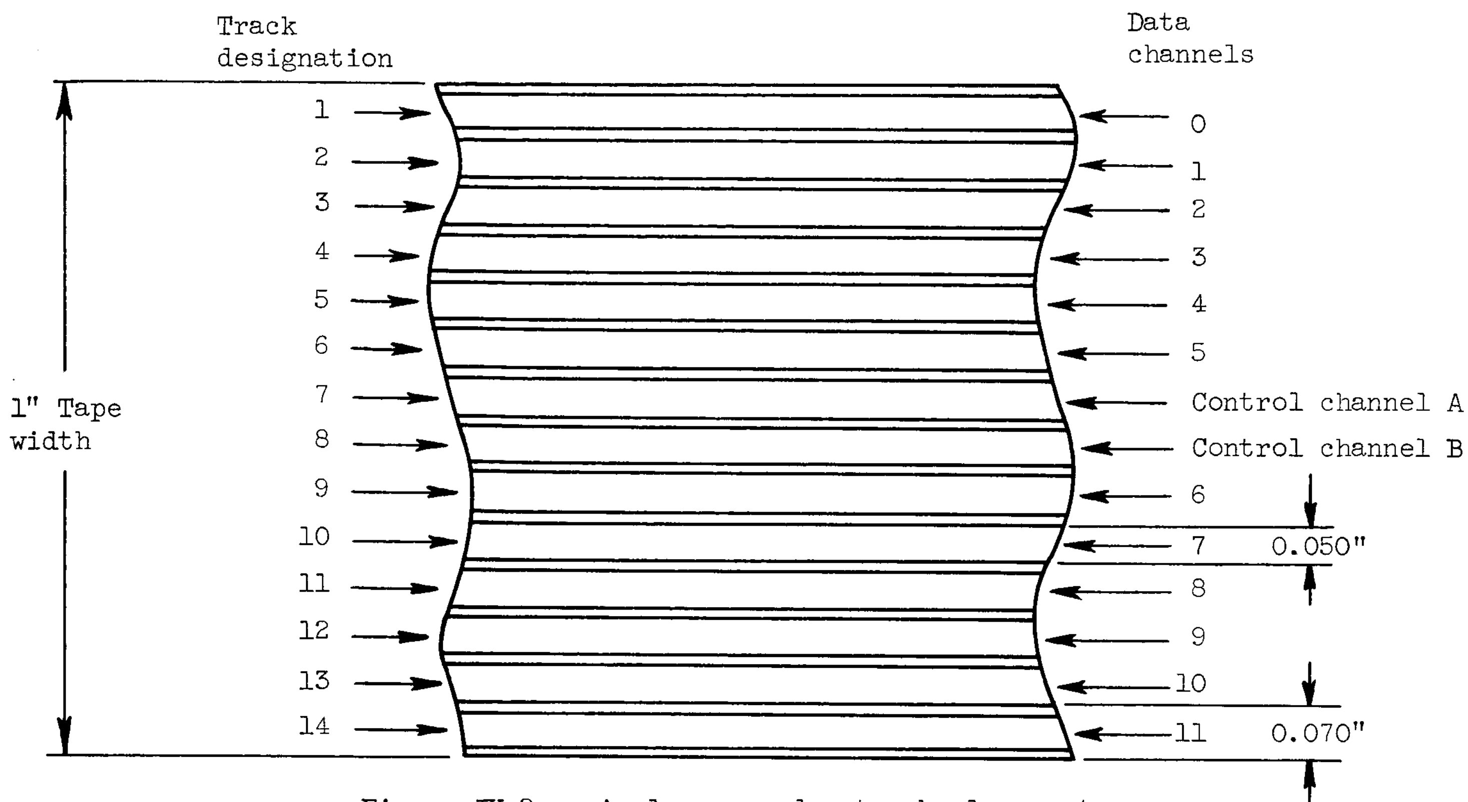


Figure IV-2. - Analog recorder track placement.

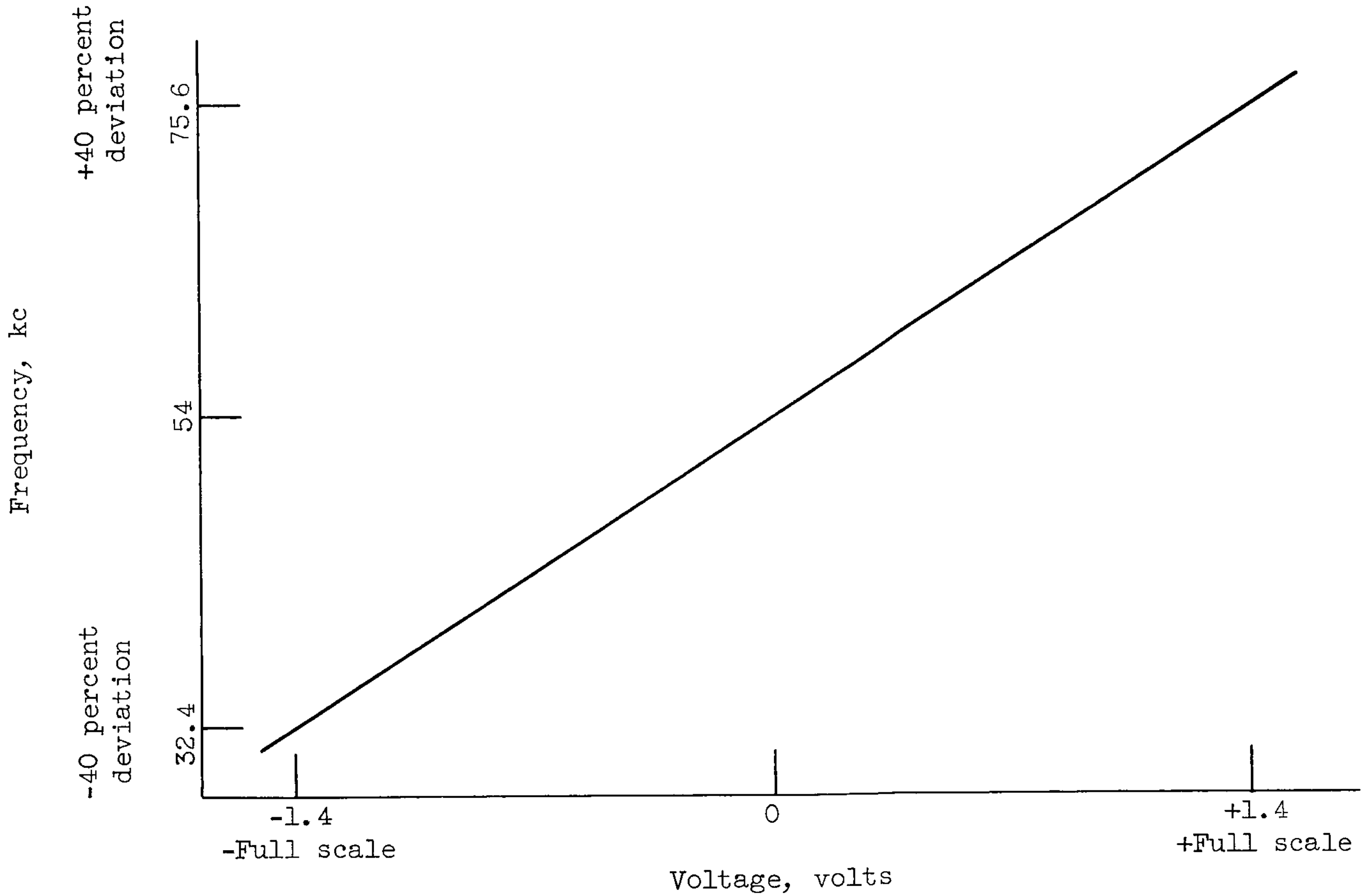


Figure IV-3. - Frequency-voltage relation for FM record modulator (shown for tape speed of 60 in./sec).

Frequency, kc

+	75.6
0	54.0
-	32.4

Test facility controls: Call (0); Take data (D-2); Stop (E-3)

Time determined by facility (D-0 to E-3)

Time, sec	0 1 • 2	2 3 4	4 5 6 7	7 8 9 10	10 D-2	D-2 D-1 D-0	D-0 D-1 D-2 E-3	E-3 E-2	E-1 E-end
Zone number		1	2	3		4	5	6	7
Zone designation	Transport starting time	Record number	Zero calibrate	Full-scale calibrate		Predata (non-usable)	Record data (usable)	Zero check	Full-scale check
Control channel A	Blank	Record number encoded, 0 0	-	-		+	Block number encoded	+	0
Control channel B	Blank	+	+	0		+	0	-	-
All data channels inputs	Transducers	Transducers	Zero voltage	Full-scale voltage	Transducers	Transducers	Transducers	Zero voltage	Full-scale voltage

Tape width

Tape direction

Figure IV-4. - Zone definition of analog transient system (for tape speed of 60 in./sec and manual mode of operation).

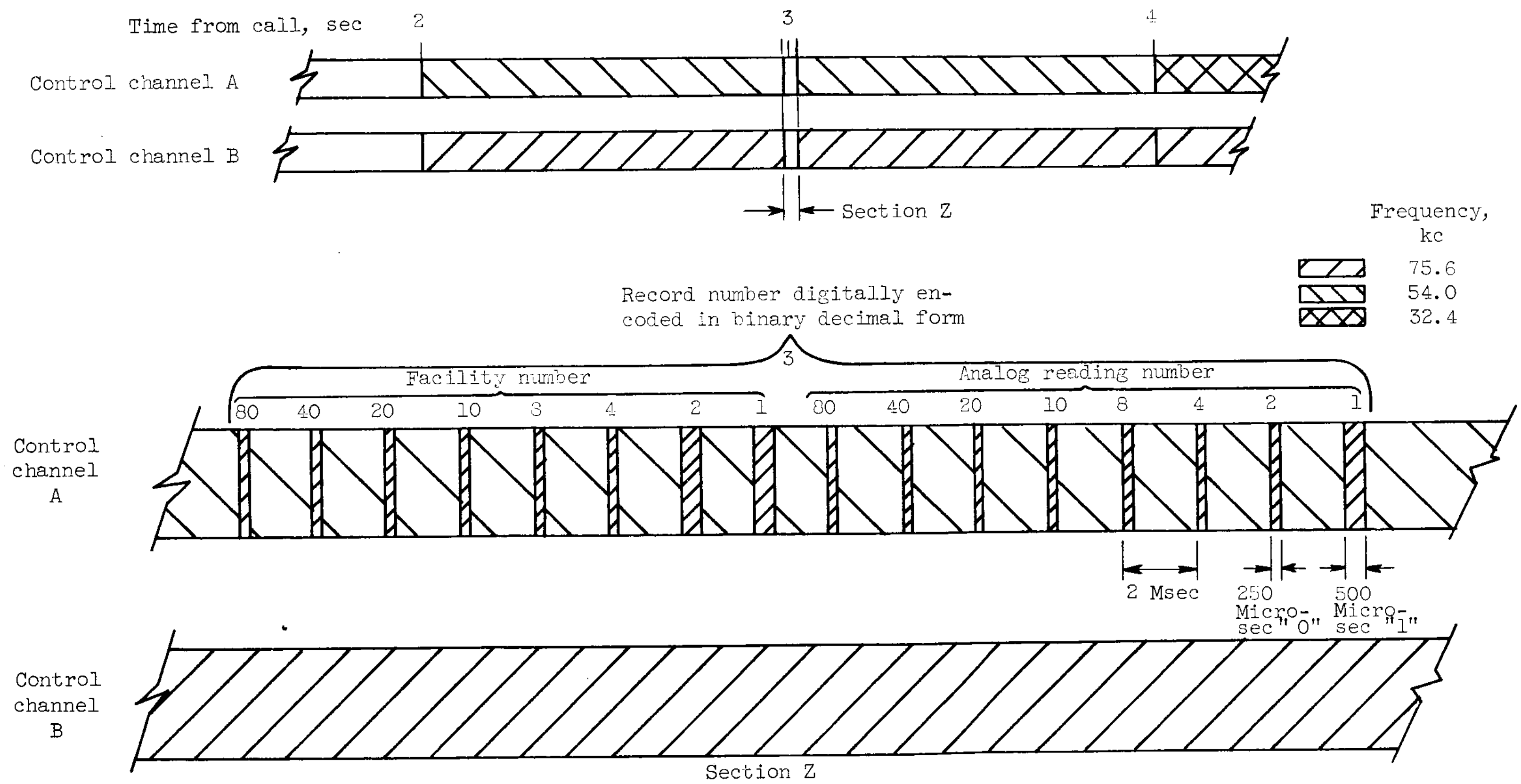


Figure IV-5. - Record number zone with expanded record number. (Record number shown, 0301.)

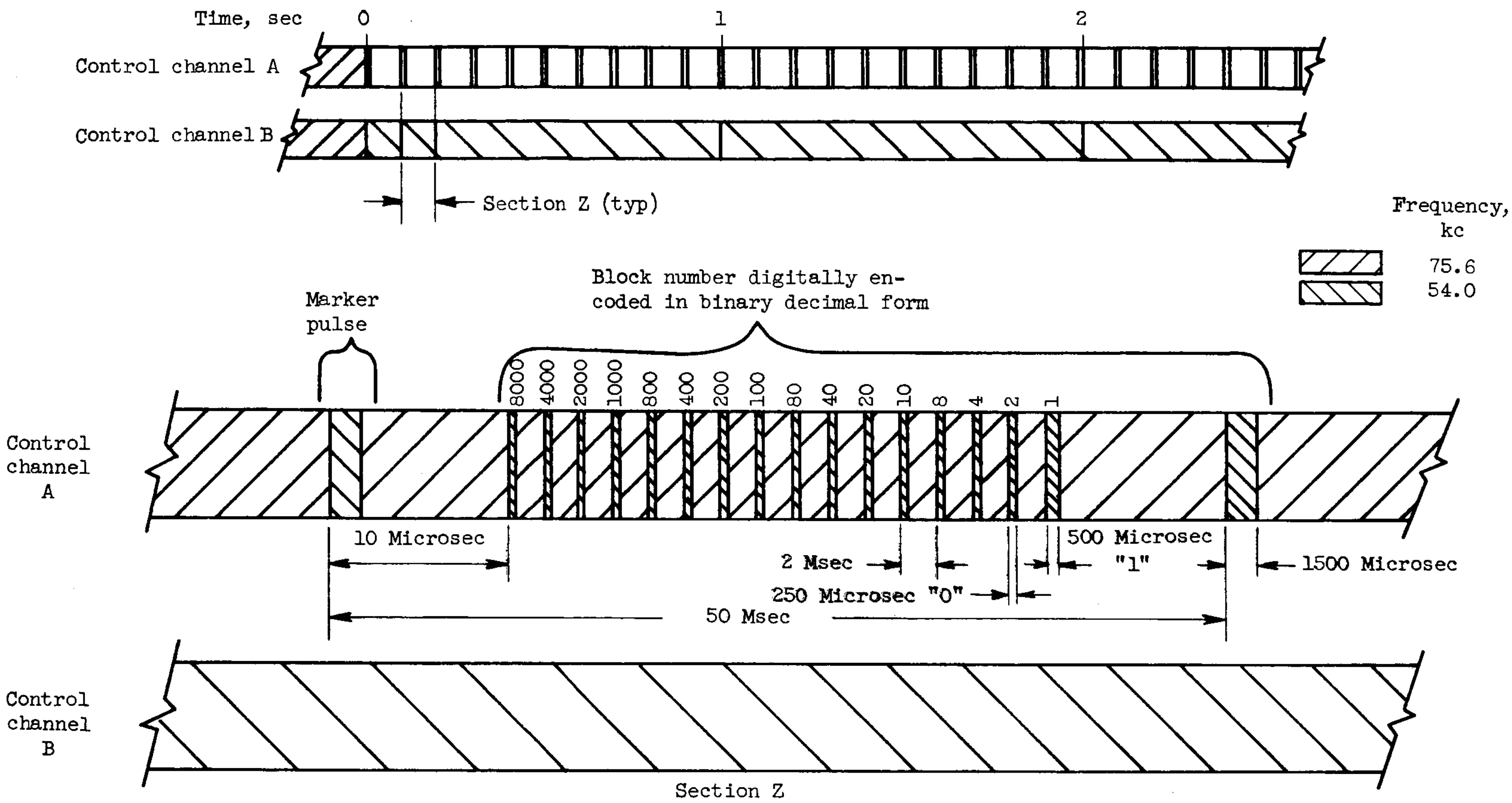


Figure IV-6. - Record data zone with expanded block number. (Block number shown 0001.)

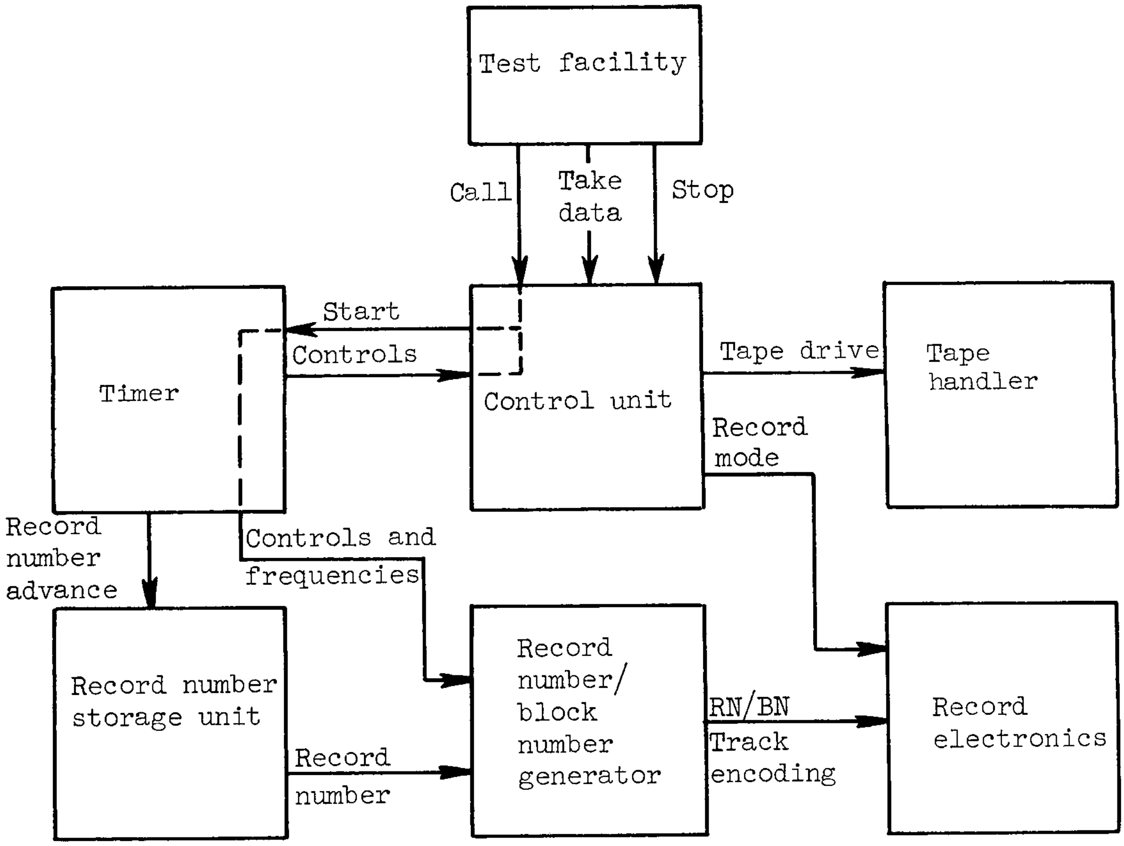
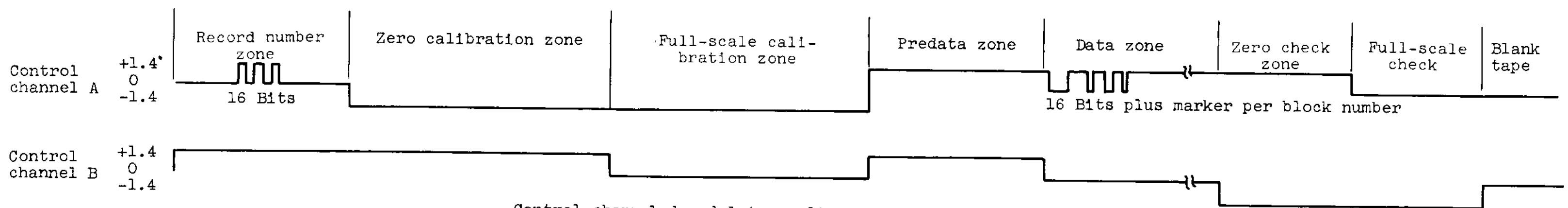
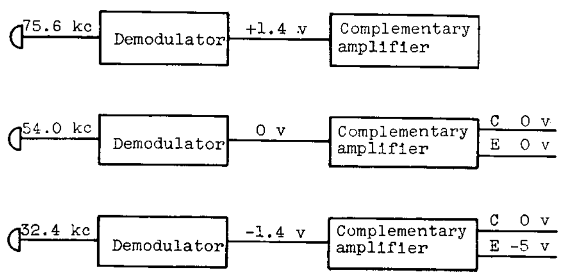


Figure IV-7. - Basic block diagram of system control.



Control channel demodulator voltage output



Complementary amplifier outputs

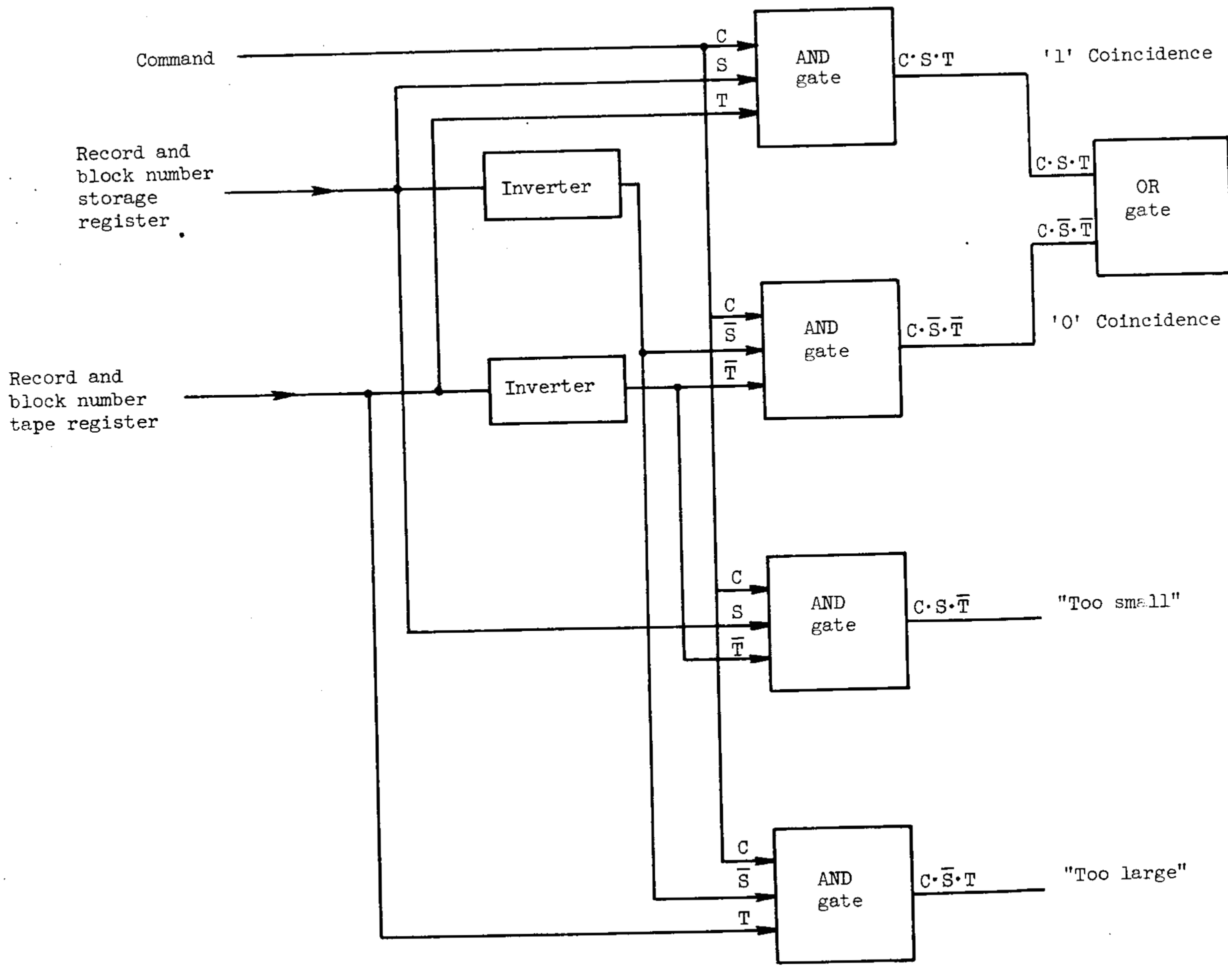
COMPLEMENTARY AMPLIFIER OUTPUT

VOLTAGE TRUTH TABLE

[0 = 0 v; 1 = -5 v.]

Zone	Amplifier A		Amplifier B	
	Output C	Output E	Output C	Output E
Record number	0	0	1	0
Zero calibration	0	1	1	0
Full-scale calibration	0	1	0	0
Predata	1	0	1	0
Data	1	0	0	0
Zero check	1	0	0	1
Full-scale check	0	0	0	1
Blank tape	0	0	0	0

Figure IV-8. - Demodulator and complementary amplifier output voltages during eight zones.



C	S	T	
1	1	1	'1' Coincidence
1	0	0	'0' Coincidence
1	1	0	"Too small"
1	0	1	"Too large"

Figure IV-9. - Logic diagram of single stage of comparator.

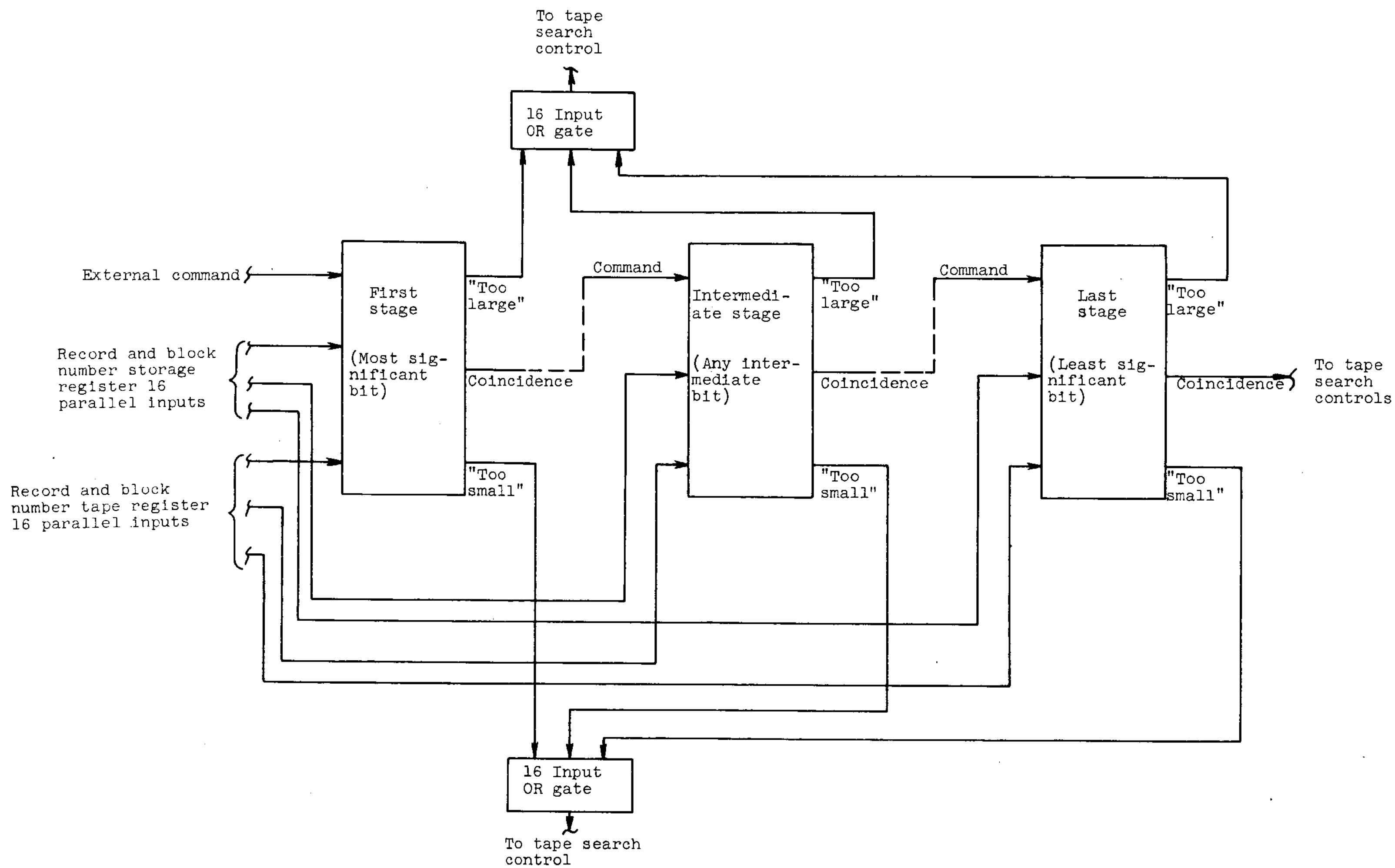


Figure IV-10. - Block diagram of comparator.

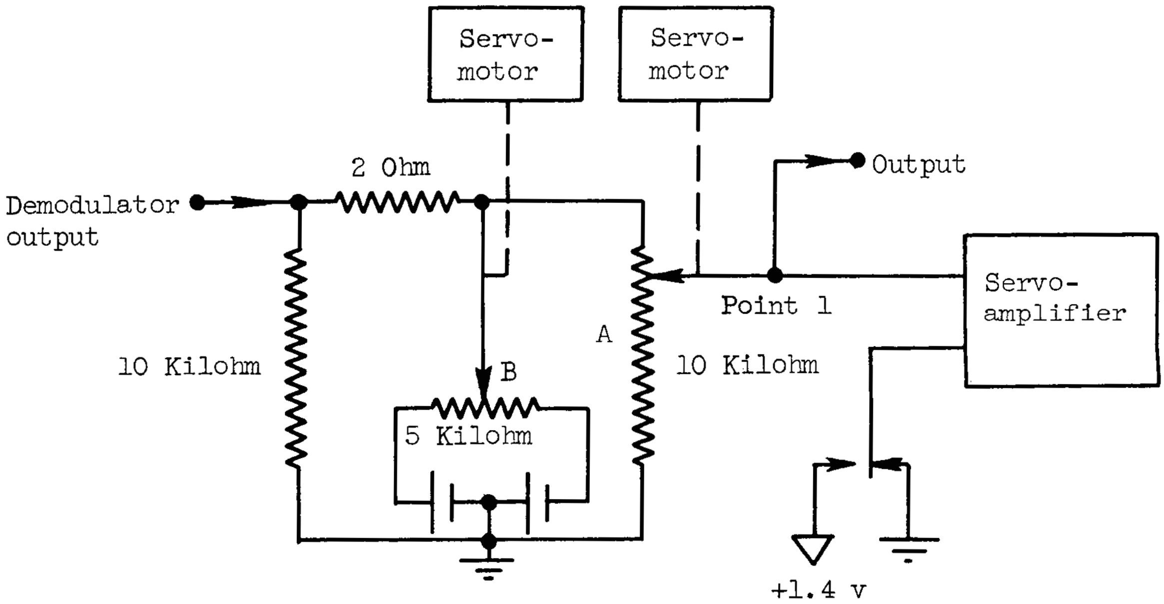


Figure IV-11. - Automatic drift correction.

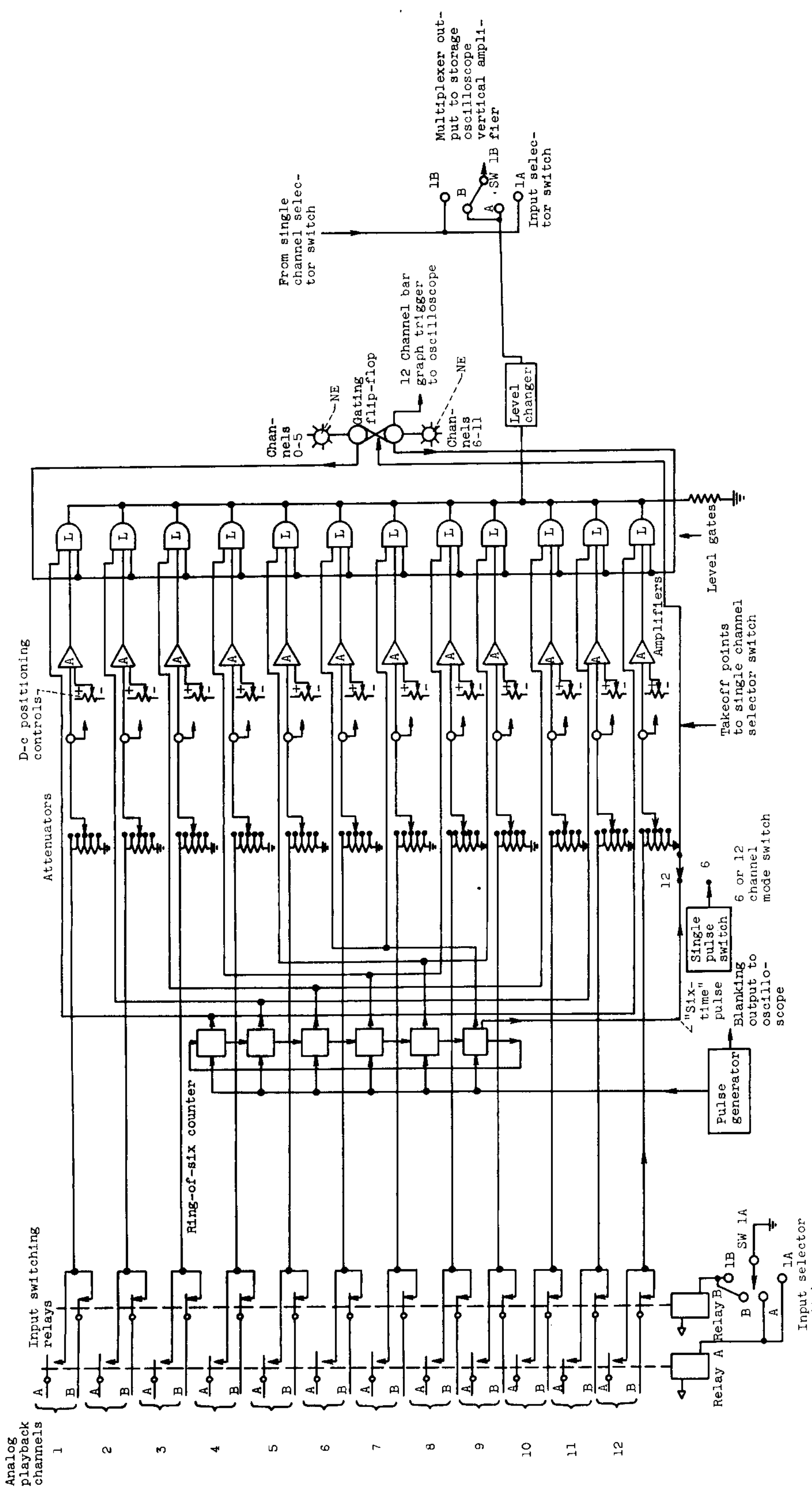


Figure IV-12. - Analog quick-look system multiplexer.